

ACQUISITION OF STUDY REPORTS FOR LITERATURE
REVIEW OF HORIZONTAL WELLS AND MODELS FOR
HORIZONTAL WELL INJECTORS AND PRODUCERS.

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EXHIBIT III

**COPIES OF THE PATENTS
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Improved methods and apparatus are provided for recovering high viscosity oils from a sub-surface earth formation utilizing horizontal well apparatus. A plurality of horizontal drill holes extend from a large diameter vertical shaft hole into the formation of interest. Steam may be injected into the formation through selectively placed conventional vertical wells terminating within the oil-bearing formation, while oil is recovered from the lateral drill holes. A noncondensable gas or cold water may be injected into the formation subsequent to steam injection to enhance the overall recovery of oil.

15 Claims, 4 Drawing Figures

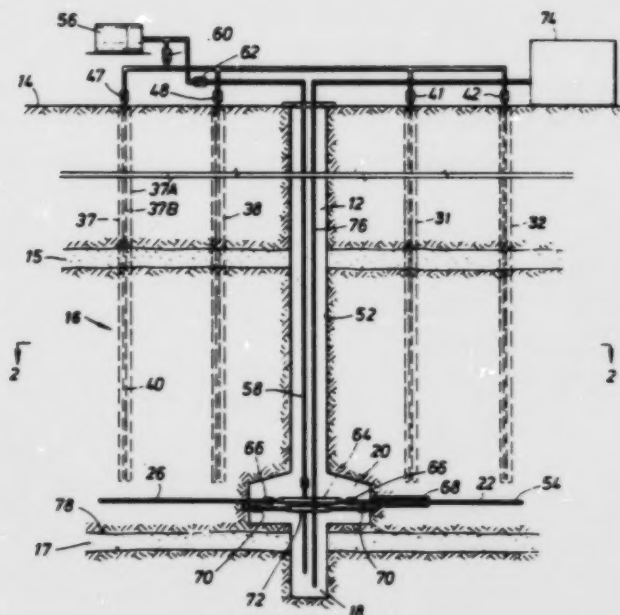


FIG. 1

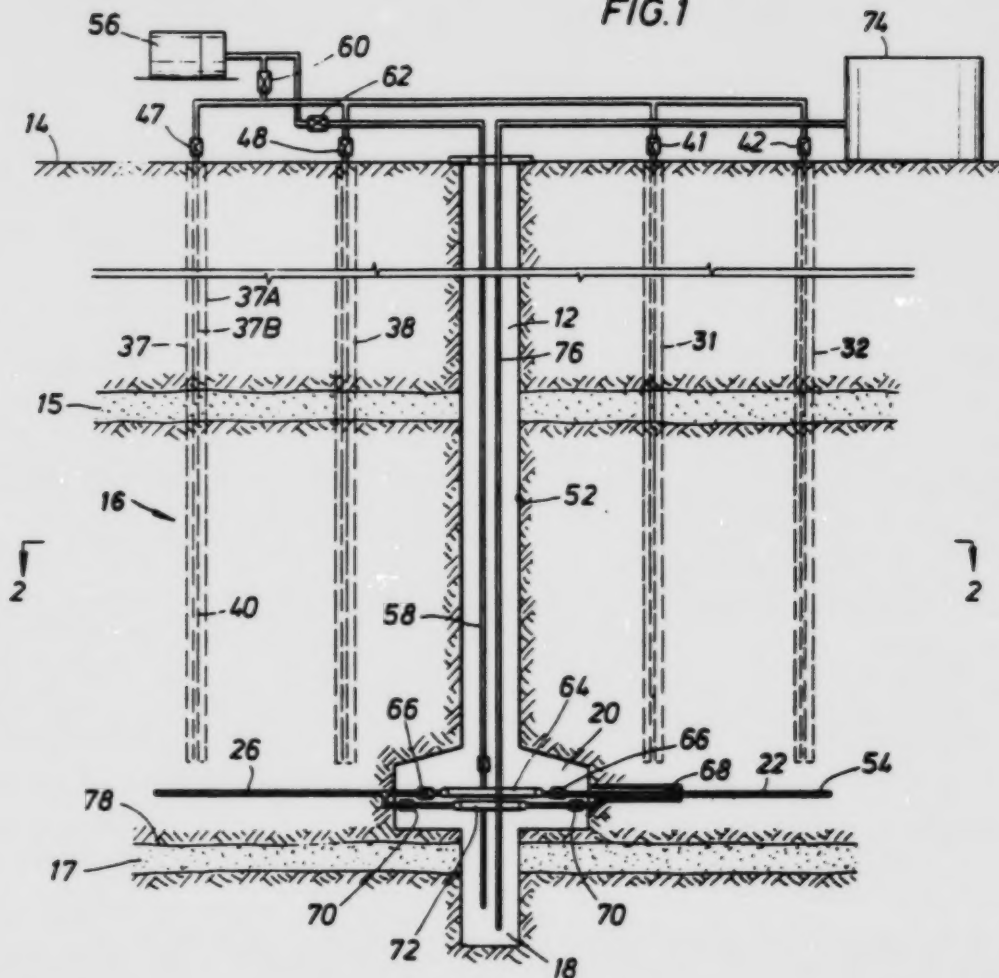
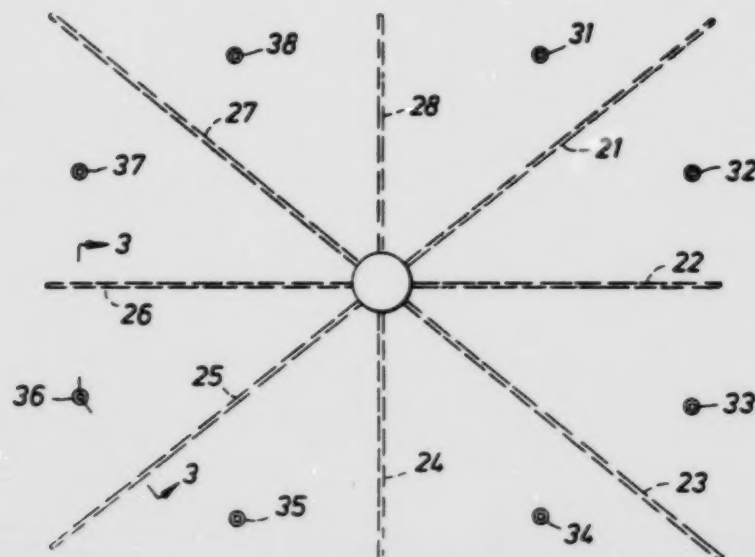


FIG. 2



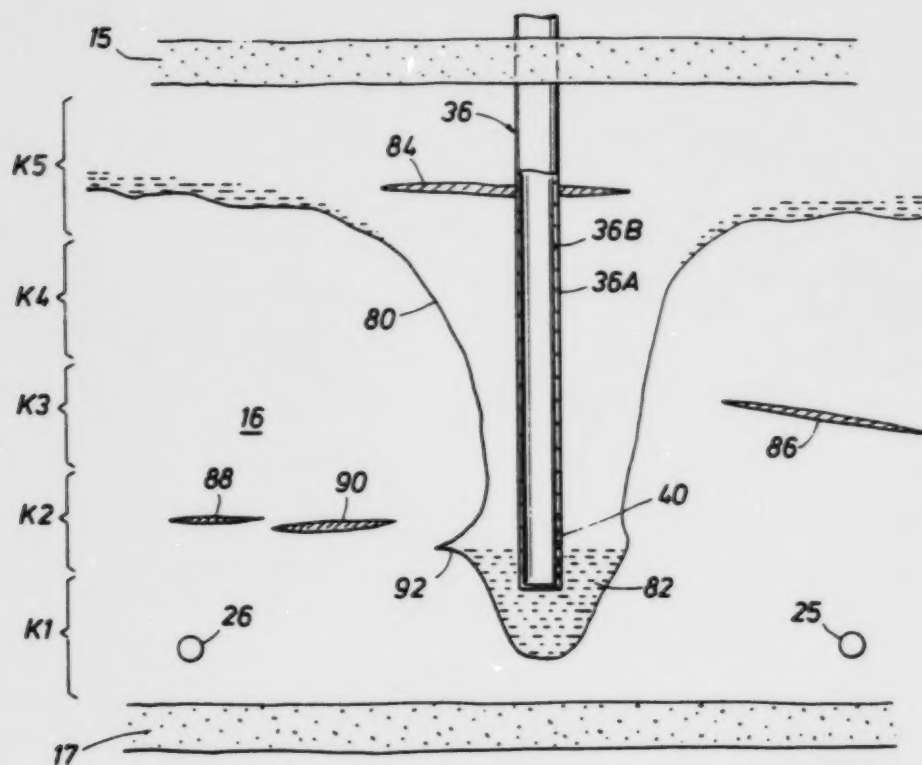


FIG. 3

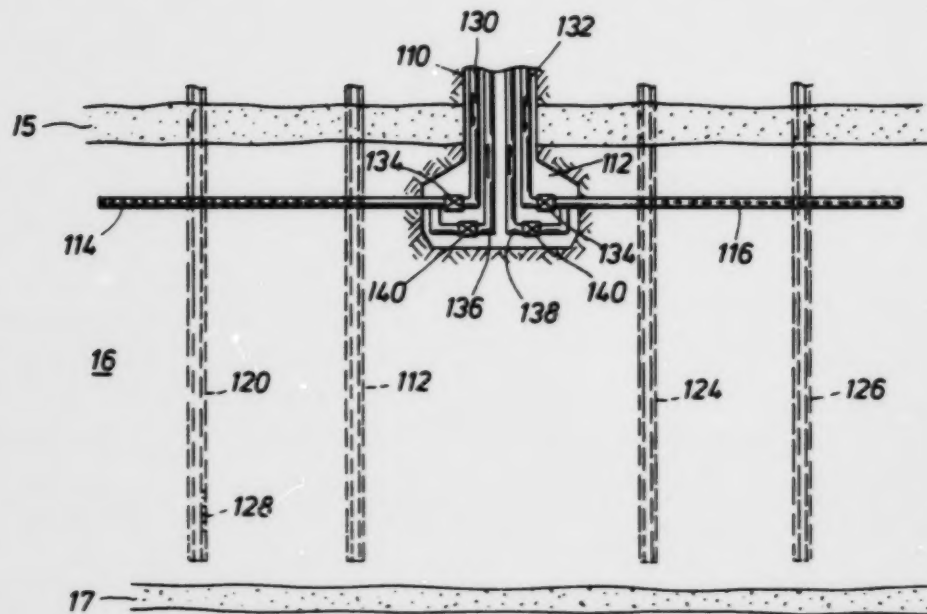


FIG. 4

niques. Also, as previously described, a substantial variance exists between drive and soak operations adapted for horizontal well technology and drive and soak operations adapted for vertical well technology. Although horizontal wells generally offer the advantage of increased efficiency of oil recovery as compared with vertical wells, the costs associated with mining and operating a horizontal well are often heretofore prohibitive. Also, although horizontal steam soak operations are generally more efficient than vertical well steam soak operations, the efficiency of prior art horizontal well soak operations, when combined with the increased economic investment for horizontal wells, is such that oil recovery may not be practical.

The problems and disadvantages of the prior art are overcome with the present invention. Novel methods are herein provided for recovering high viscosity oils from a subsurface earth formation, wherein a greater percentage of the oil can be recovered from the formation, and can be recovered in a shorter time period.

SUMMARY OF THE INVENTION

In an ideal embodiment of the present invention, a vertical mine shaft or the like is bored or dug from the surface to the formation of interest, whereby personnel and equipment can reach the base of the formation. More particularly, the portion of the borehole across the formation is preferably enlarged laterally so as to provide a work chamber of a shape and size sufficient to permit operations to be conducted at the base of the formation in an appropriate manner, subject to whatever shoring may be required under particular conditions. Thereafter, drill holes are bored into the face of the formation and radially about the chamber in the lower portion of the formation. The plurality of substantially horizontal drill holes serve as recovery lines enabling the oil in the formation to efficiently flow to the large diameter bore hole, so that the oil may subsequently be pumped to the surface by conventional means. The invention is particularly suitable for recovering high viscosity oils, which are generally inclusive of both medium gravity oils having an API range of 20° to 25°, and heavy crude oils having an API range of 20° or less.

The particular spacing and arrangement of the drill holes will, of course, depend on the size and lithology of the formation of interest, but it is a feature of the invention to provide approximately eight different radially extending drill holes from each shaft hole, and to further extend such drill holes to a location adjacent the ends of similar radials extending from an adjacent vertical shaft hole. As will hereinafter be described in detail, each group of radial drill holes will then define a rectangular pattern within the field, and thus the field may be effectively "covered" with a blanket of such rectangular patterns. The radials themselves will usually extend in a generally horizontal direction, although it may be preferable to extend the radials parallel with the lower plane of a tilted formation, e.g., two feet above the bottom surface of the tilted formation. Alternatively, the radials may be positioned at a slight upward angle relative to their respective shaft hole in order to accommodate gravity flow of the oil from the formation.

According to one embodiment of this invention, steam is injected into the formation from a plurality of vertical wells terminating within the oil bearing formation. Eight drill holes extend horizontally into the lower portion of the formation from a large diameter shaft

hole, and serve as recovery laterals. The vertical wells terminate at an elevation slightly higher than the horizontal laterals, and are horizontally spaced between respective recovery laterals. The steam may be injected simultaneously into the formation from that portion of each of the vertical wells within the oilbearing formation. The injected steam rises vertically within the formation due to gravitational forces, and also permeates the formation horizontally as steam is continually injected. Steam is injected into the formation from the vertical wells while oil is recovered from the horizontal laterals, and the oil is thereby recovered utilizing a dynamic driving process.

This embodiment of the invention is of significant advantage over horizontal driving techniques, since the process does not principally rely on driving the oil horizontally within the formation. The process described herein is thus not burdened by the detrimental effects of fingering and gravity override common in horizontal drive techniques. Also, the vertical wells enable the oil in the formation to be effectively heated to decrease the viscosity of the oil in the formation and thus reduce the force necessary to drive the oil to the recovery laterals. The oil is thereby driven both vertically and horizontally toward the recovery laterals, to enhance the overall recovery efficiency.

A principal benefit to the above technique is that energy is not wasted moving oil about in the formation. Thus more oil may be recovered with less steam and therefore less fuel costs. Recovery of oil according to the techniques herein described requires a large initial investment of time and monies, and also a substantial continued investment of time and machinery as long as recovery process is active. Thus, the present invention has the advantage of substantially increasing the production rate which improves the rate of return on the investment and thereby enhances the economics of the recovery process. The net result is that less economic investment in equipment and fuel is used to recover a higher percentage of oil from the formation.

A particular feature of this invention is to provide methods and apparatus that allow for increased production rates of recovering high viscosity oil from subsurface earth formations. Higher rates of recovery for oil often yield an increased overall efficiency of the recovery process, as long as gravity override and viscous fingering can be avoided.

It is another feature of this invention to provide a plurality of laterals extending radially into a portion of an oil bearing formation from a large diameter shaft hole, wherein the laterals serve as recovery lines for the oil removed from the formation.

Yet another feature of this invention is to provide a method of recovering high viscosity oil from a formation utilizing recovery laterals wherein oil is repeatedly moved closer to the recovery laterals during the recovery operation.

It is another feature of the present invention to provide improved methods and apparatus for recovering high viscosity oils, wherein a driving fluid is injected into the formation from a plurality of conventional vertical wells, and oil is efficiently recovered from a plurality of substantially horizontal boreholes.

These and other features and advantages of the present invention will become apparent from the following detailed description, wherein reference is made to the figures in the accompanying drawings.

METHOD AND APPARATUS FOR RECOVERING HIGH VISCOSITY OILS

RELATED PATENT APPLICATIONS

This is a continuation-in-part of co-pending U.S. patent application Ser. No. 108,815, filed Dec. 31, 1979, now abandoned, which is a continuation-in-part of U.S. patent application Ser. No. 940,390, filed Sept. 7, 1978, now U.S. Pat. No. 4,257,650.

BACKGROUND OF THE INVENTION

This invention relates to methods and apparatus for recovering high viscosity oils from subsurface earth formations, and more particularly relates to improved methods for recovering such oils by employing a large diameter shaft hole and a plurality of horizontal drill holes extending radially from the shaft hole.

Early disclosures relating to the recovery of petroleum substances by utilizing a large diameter shaft hole and a plurality of substantially horizontal drill holes are provided in U.S. Pat. Nos. 1,520,737 and 1,634,235, and a paper published by Ranney in the *Petroleum Engineer* in 1939 entitled "The World's First Horizontal Well". These publications propose the drilling of a large diameter shaft into an oil-bearing formation and then drilling radial drill holes into the formation. More recently, U.S. Pat. Nos. 4,020,901; 4,099,570; 4,099,783; 4,116,275; 4,160,481; and 4,201,420 provide improved systems for recovering petroleum substances employing large diameter shaft holes and radial drill holes.

Some of the above processes, however, suffer limitations relating to restrictions on the rate of introducing the injected fluid into the formation, which reduces the oil recovery rate. The techniques described in the above-cited patents may be suitable for recovering oil in some formations, but are not believed to be economically feasible for recovering oil from many formations. More particularly, such techniques are believed to recover a relatively low percentage of the oil in the formation, and many of these techniques demand high fuel requirements which further reduce the net oil recovery rate.

Oil recovery techniques utilizing conventional vertical wells can be generally classified as "drive" operations or "soak" operations. In a "drive" operation, a fluid is generally injected into the formation at a first location to form a wall for driving the oil in the formation toward recovery at a second location. The objective of a drive operation is to form a displacing fluid boundary and then drive the boundary through the formation utilizing the pressure of the injected fluid. Thus, in a dynamic drive operation, fluid is injected at a first point while oil is being recovered from a second point.

A major problem with most dynamic drive operations is that care must be taken to keep the injected fluid front in a wall configuration during the driving process. In operation, several factors naturally contradict the ideological driving wall of the dynamic drive operation, including variance in formation matrix, density and viscosity variations between the injected fluid and the oil in the formation, pressure and temperature changes about the formation, and gravitational forces.

When the driving wall breaks down, the phenomenon is typically referred to as either "fingering" or "gravity override", which are discussed in detail in the co-pending patent applications. A breakdown of the dynamic

driving wall causes a significant reduction in the oil recovery efficiency of the dynamic driving process, and is a principal reason for its limited applicability.

In conventional vertical well "soak" operations, a solvent or steam may be injected into the formation for the purpose of reducing the viscosity of the oil, thereby allowing the oil to flow by gravity to recovery lines. "Soak" operations are generally not concerned with generating a wall of injected fluid, but are principally concerned with filling the formation with the soaking fluid to reduce the viscosity of the oil throughout the formation. In soak operations, the reduced viscosity oil generally flows by gravitational forces to recovery wells, and may be recovered at the same locations fluid is injected. Since a dynamic drive is not desired for a soaking process, a soaking fluid is generally not injected during the time interval in which oil is being recovered.

Soak operations are generally burdened, however, with relatively poor oil recovery efficiencies. Thus, it is not uncommon to soak a formation several times over a period of years. The cost of the fuel to generate steam is a major deterrent to the economic feasibility of soak operations. In addition, the slow rate of recovery common to soak operations substantially increases the cost of recovering oil, since expensive steam generating and water treatment equipment must be available during the life of the soak operation.

Conventional vertical well soak and drive techniques, when applied to horizontal well technology, are subjected to additional and/or different problems. One of the major problems with soak technology in conventional vertical wells is that the steam must invade or sweep through all the formation, and does not inadvertently rise over a portion of the formation because of the low density of steam. In horizontal wells, on the other hand, steam may be injected into the bottom of the wells along the length of the laterals, and thus the formation is more effectively saturated with steam since the steam rises naturally through the formation. Thus, horizontal well operations are not typically concerned with problems associated with soaking the entire formation, as in the case of conventional vertical well soak operations. Also, horizontal well soak operations are generally thought to be much more efficient than vertical well soak operations, since oil may be recovered over the long length of the laterals at the bottom of the formation, as compared to the points of recovery provided at the bottom of a formation by conventional vertical wells. Nevertheless, many horizontal well soak operations suffer from slow recovery rates and poor overall recovery efficiency.

Drive technology also becomes substantially altered when adapted to horizontal well configurations. Driving horizontally between horizontal wells commencing from a large diameter vertical well may not be practical because of difficulty in maintaining an effective wall of driving fluid. Also, since the spacing between adjacent laterals will vary with the distance from a common large diameter vertical well, the conventional univelocity wall driving techniques may not be applicable. Further, the close proximity of the laterals near a common diameter vertical well may result in steam fingering horizontally and short-circuiting between adjacent laterals.

The distinction between drive and soak operations is not always as simplistic as described above, although fundamental differences exist between these two tech-

IN THE DRAWINGS

FIG. 1 is a simplified pictorial representation, partly in cross section, of an exemplary installation for recovering oil from a subsurface earth formation according to one embodiment of the present invention.

FIG. 2 is a horizontal or plan cross-sectional representation of a portion of the apparatus depicted in FIG. 1.

FIG. 3 is a simplified representation of a portion of the apparatus depicted in FIG. 1 during the oil recovery process.

FIG. 4 is a simplified representation of another embodiment of the present invention.

DETAILED DESCRIPTION

In FIG. 1, there may be seen a pictorial representation of an oil recovery system embodying the concepts of the present invention. In particular, the apparatus depicted in FIG. 1 may be utilized for recovering high viscosity oils from subsurface earth formations. A substantially vertical mine shaft 12 is drilled or bored from the surface 14 to the oil bearing formation 16. The oil bearing formation 16 may typically be hundreds of feet below the surface 14, and is shown to be bounded by an upper layer 15 and a lower layer 17 of rock or shale deposits, which are generally impregnable to fluid flow. As seen in FIG. 1, the mine shaft 12 is drilled through the oil bearing formation 16, and terminates at sump hole 18. The shaft 12 is expanded at the bottom portion of the formation to form a lower work chamber 20. A plurality of lower laterals 22 and 26 may be drilled into the formation from the lower work chamber 20.

The walls of the shaft 12 may be conveniently sealed with sections of bolted or welded steel plates to form a casing 52, or may be lined with an appropriate material such as gunite, to prevent caving or other collapse of the walls of the shaft 12. The diameter of the shaft 12 is preferably of a size sufficient to accommodate the passage of men and equipment from the surface 14 to the interior of the work chamber 20. The mine shaft 12 and the work chamber 20 may be constructed in the manner further described in U.S. Pat. No. 4,160,481. Each of the lower laterals extending from the work chamber 20 contains perforations 54 for recovering oil from the formation 16.

A steam generator 56 on the surface may be utilized to inject a steam mixture into the formation through vertical injection wells 31-38, each injection well including a bore hole A and an injection conduit B. It may be seen from FIGS. 1 and 2 that each of these vertical bore holes 31A-38A are drilled from the surface 14 through the rock layer 15 and terminate within the formation 16. As explained in further detail below, each injection conduit 31B-38B may extend into a portion of the formation slightly above the horizontal laterals. Each injection conduit may be provided with perforations 40 for that portion of the injection conduit within the oil bearing formation for allowing steam to enter the formation. Respective valves 41-48 may be used to regulate and control the flow of fluid from the generator 56 through each vertical well and into the formation.

It is also within the concept of this invention to initially inject steam into the formation from the horizontal laterals. Steam line 58 is therefore provided within the main shaft 12 and connects the generator 56 to the horizontal laterals. Main valve 60 between the generator 56 and the control valves 41-47 (representative

valves 41, 42, 47 and 48 depicted in FIG. 1) may be regulated to control steam flow to the vertical wells. Valve 62 may be controlled to regulate steam flow to annular manifold 64, which supplies steam to each of the laterals. A remotely controlled valve 66 is provided between the manifold and each lateral, to separately regulate steam flow to individual laterals. Perforations 54 in the laterals allow steam to enter the formation along the length of the laterals. Alternatively, outer casing 68 may be provided over a portion of one or more of the laterals to limit the location of steam injection. For instance, outer casing 68 may be provided over the first one-third length of each lateral, which would thereby allow steam to enter the formation from only the remaining two-thirds portion of each lateral spaced farthest from the work chamber 20.

As explained in detail below, oil may be recovered from each of the laterals 21-28. The laterals may extend radially from the work chamber 20 into the formation 16, thereby "blanketing" a portion of the formation, as subsequently described. Regulating valve 70 may be provided for each of the laterals, so that the recovery of oil from individual laterals may be controlled. Thus, if valve 66 were closed and valve 70 open, it may be seen that oil may be recovered from the formation via lateral 26. Oil may then flow from the laterals into return manifold 72, and thereafter be pumped to collection tank 74 via recovery line 76. Alternatively, oil may flow from the manifold 72 to the sump hole 18, and thereafter be pumped to the surface. If desired, each of the valves 70 may be provided with a conventional flowmeter, so that the oil recovery rate from each of the laterals may be monitored.

Referring now to FIG. 2, there is shown a horizontal cross-sectional view of a portion of the apparatus depicted in FIG. 1. The horizontal recovery laterals 21-28 form a generally rectangular blanket, although a circular, square, or other suitable blanket configuration is possible. Each of the laterals preferably lies within a plane generally conforming to the boundary surface 78 of the formation 16 and the lower layer 17, and typically may be 2 feet or less above the surface 78. In FIG. 2, it may be seen that the vertical wells 31-38 may be spaced between the horizontal laterals, and that the injection wells are spaced geographically to cover the area to be blanketed by the horizontal laterals. In particular, each of the injection wells 31-38 may be equally spaced in a horizontal direction between two of the lower laterals, and the radial distance from the center of the shaft 12 to each of the vertical wells may be 60% to 95%, and preferably between 80% to 90%, of a distance from the center of the shaft 12 to extremity of the blanketed lateral well configuration. The vertical wells are, therefore, preferably spaced between the recovery laterals and toward the periphery of the blanketed zone to increase the efficiency of the recovery operation.

The laterals 21-28 blanket a portion of the formation from which oil is recovered. Typically, the laterals will radiate from the working chamber 20 to enable a substantially horizontal blanket to be established having an area of approximately 25 acres. Recovery of oil according to the techniques described herein requires a considerable investment of labor and equipment. The drilling costs for the mine shaft 12 and laterals 21-28, and the costs associated with maintenance and operation of the steam generator 56 are high, and therefore a high percentage of the oil within the formation should be recov-

ered in a relatively short period of time if the operation is to be economically feasible.

Because of the aforementioned drilling costs and the equipment costs, and because of variable formation characteristics, it may be economically desirable to recover oil from a single recovery well or mine shaft 12, and its associated recovery laterals, utilizing the capacity of steam generating equipment designed for that recovery well. In other words, the present invention is especially suitable for recovering oil from horizontal laterals blanketing a certain area and utilizing equipment principally adapted for servicing only that certain area. It is therefore a feature of the present invention that the full design capacity of the steam generating equipment 56 be utilized during most, if not all, of the time oil recovery operations are proceeding from the mine shaft 12 and laterals 21-28. The oil in that portion of the formation may therefore be efficiently recovered, without regard for the operation of possible adjacent recovery wells.

Referring again to FIG. 1, it may be seen that the vertical injection wells may extend into a lower portion of the formation. For instance, if a formation 16 were 123 feet thick, and the recovery laterals 21-28 were 3 feet above the surface 78, the vertical wells 31-38 may extend to a depth of approximately 20 feet above the recovery laterals. In this embodiment, each of the eight vertical wells will expose 100 feet of perforated pipe to the formation. As explained further below, the steam generator 56 may evenly distribute steam to each of the injection wells, so that in this embodiment steam may enter the formation from 800 feet of perforated pipe.

Although formation receptivity to injected steam will depend on particular formation characteristics, most formations will easily be able to initially absorb the full capacity of the steam generator 56 since a long length of perforated pipe is provided within the formation. Thus, the vertical injection wells of the present invention will be fully able to transmit the full capacity of the steam generator 56 to this formation, which may not be possible if the injection wells each terminated in the upper portion of the formation. As steam enters the formation from the vertical injection wells, oil within the formation is progressively pushed away from the vertical wells and the formation becomes heated. As steam is injected into the formation, therefore, the oil becomes less viscous and formation receptivity to injected steam increases in the vicinity of the vertical wells. After some period of time, it is thus possible to fully utilize the capacity of the steam generator 56 and inject the steam into the formation from only a portion of each of the vertical wells within the formation.

One method of recovering oil according to the present invention will now be described. Oil may be initially injected into the formation through perforations already provided within that portion of each vertical well within the oil bearing formation 16, or through perforations within a substantial portion of each vertical well within the oil bearing formation. As explained above, the length of perforated pipe within the formation enables the full capacity of a steam generator 56 to be utilized, so as to reduce the time required for recovering a high percentage of the oil within the formation.

As steam enters the formation 16 from a given vertical well, the steam will tend to rise within the formation to form a gas cap below the rock layer 15. Continued injection of steam will not only tend to reduce the oil viscosity in the formation with the vicinity of the recov-

ery laterals, but the injected steam will also migrate upward to form a gas cap for driving the oil downward toward the recovery laterals. Each of the eight vertical wells 31-38 therefore contributes to the formation of a continuous gas cap below the rock formation 15 covering the entirety of the area blanketed by the recovery laterals 21-28.

Steam may be continually injected into the vertical wells while the recovery laterals are open for recovering oil. Thus, the process described herein is a dynamic driving operation, and is principally a dynamic vertical driving operation with the injected steam driving the oil downward to the recovery laterals.

FIG. 3 depicts the cross-section of a portion of the apparatus shown in FIG. 2 at some time period during the recovery operation. One-eighth of the capacity of the generator 56 may be injected into the formation through vertical well 36. The injected steam will generally tend to rise within the formation to form a gas cap of injected steam below rock layer 15. Oil within the formation will thus be driven vertically downward by the gas cap, and to a lesser extent will be driven horizontally from the vertical well 36 toward the recovery laterals 25 and 26.

Some of the steam may condense near the steam/oil interface 80, which serves as a driving fluid front for the driving operation. The interstitial water 82 may generally descend along the steam/oil interface to a location adjacent to the bottom of the vertical wells. The steam/oil interface or front during the driving process may be compared to a plurality of widening mushrooms each centered at an individual vertical well, with the steam layer adjacent the rock formation 15 forming the cap of the mushrooms. Alternatively, the steam/oil interface during the driving process may be viewed as a widening cone at each vertical injection well in conjunction with an increasingly thick steam cap driving the oil downward.

In this manner, oil may be effectively driven from the formation. Even though the formation 16 may contain lenses 84, 86, 88 and 90 which are generally impregnable to fluid flow, these lenses will not significantly affect recovery of oil utilizing the vertical drive in process, since the driving force of the steam will force the oil around the lenses and the steam will then engulf the lens.

A significant advantage of the vertical wells 31-38 is that the viscosity of the oil within the lower half of the formation is reduced by the injected steam and maintained at a reduced level during the driving process. Thus, extending the vertical wells into the lower portion of the formation may enable the oil to be more easily driven from the formation than if the vertical wells terminated near the top of the formation and the driving process commenced when the lower portion of the formation was "cold." Another advantage of the downward extending vertical wells 31-38 is that oil is, to some extent, moved horizontally during the steam driving process. This directs the oil toward the recovery laterals, so that oil in the lower portion of the formation between adjacent laterals may also be effectively recovered.

As stated above, the present invention may be effectively employed by utilizing a driving fluid and driving the oil vertically toward recovery laterals. In a vertical driving technique, the pressure gradient within the formation may be altered by the injected fluid to force the oil toward the recovery lines. Because of the weight of

the oil in the formation, the pressure near the upper section of the formation will generally be less than the pressure in the lower portion of the formation. By way of illustration and referring to FIG. 1, if a formation 16 were 60 feet thick and the pressure at the top of the formation just below the layer 15 was 15 PSig, the pressure at the bottom of the formation adjacent to the layer 17 may typically be 40 PSig because of the pressure gradient of the oil in the formation 16.

According to the vertical steam driving techniques discussed herein, drawing the oil from the recovery lines 21-28 will produce a pressure differential sufficient to force or drive the oil vertically. Preferably, a pressure differential of 100 PSI or more is achieved during the driving process between the pressure at the place of injection and the pressure at the place of recovery within the formation. The preferred pressure differential will vary depending on specific characteristics of the oil and the formation, and typically a pressure differential of 200 PSI to 400 PSI will be desired. The maximum pressure at the place of injection is generally limited for safety reasons to 1 PSI per foot of overburden. For instance, if the rock layer 15 is 400 feet below the surface 14, it may be desired to limit the pressure of the injected steam in the upper portion of the formation 16 to 400 PSI.

Vertical drive, according to the present invention, may be properly utilized without concern for gravity override, even with injection rates far exceeding the injection rate employed in conventional horizontal drive techniques. In the embodiment described above, the density contrast between the oil and the injected fluid is deliberately utilized during the driving operation to increase the efficiency of the recovery processes, while the same density contrast may result in gravity override in horizontal drive operations thereby decreasing the efficiency of horizontal drive recovery processes. Also, since the oil is being driven vertically downward, the likelihood of viscous fingering during the driving operation is substantially eliminated since (a) a uniform blanket of driving fluid is formed at the top of the formation, (b) the interstitial water 82 acts, in part, as a face for driving the oil downward in the formation, and (c) the oil is being driven vertically downward, and the injected fluid will not tend to pierce through the formation 16 because the injected fluid is less dense than the oil below the injected fluid. Further, as explained below, viscous fingering prior to the driving operation increases the efficiency of the recovery process according to the present invention, rather than being detrimental to the recovery efficiency as in horizontal drive techniques.

A vertical drive operation according to the present invention benefits from a greater steam/oil interface area than that commonly associated with horizontal driving techniques. For instance, when conventional horizontal drive between vertical wells is utilized in a formation 60 feet thick, the area or face of the driving formation is typically approximately 12,500 square feet per acre. If vertical drive is practiced according to the present invention, the area or face of the driving front increases to approximately 43,000 square feet per acre. Thus, if the same injection rate per area of driving front is utilized, fluid is injected at approximately 3.5 times the rate as in conventional horizontal drive. Moreover, since the oil is being driven vertically rather than horizontally, the injection rate per area of the driving front

may be substantially increased since viscous fingering is substantially eliminated during the driving operation.

A larger driving face area, therefore, enables more driving fluid to be injected into the formation while maintaining a relatively low, stable driving velocity through the formation. Also, as previously mentioned, the driving velocity may be substantially increased when compared to horizontal drive since vertical driving minimizes the likelihood of viscous fingering. Further, the fluid may be injected at higher pressures and at higher rates than realized in the prior art, which improves the efficiency of the recovery process. For instance, steam which may have been injected at 25% quality in horizontal drive operations may efficiently be injected at the higher rates and with greater steam quality, e.g., 80%, than in the prior art. Also, superheated steam may be used as the injected fluid.

In the methods described above, oil recovery is based on the vertical drive process, which may be simplistically described as injecting fluid in the formation for driving the oil downward while recovering oil from a set of substantially horizontal laterals. Although this invention is principally directed to an improved vertical driving technique, it is within the concept of my invention to improve the efficiency of the vertical driving process by providing for a limited soak cycle for the plurality of lower laterals 21-28. For instance, if a vertical downward drive of the oil is to be achieved, it may be initially desirable to inject steam in the lower laterals 21-28 to soak the formation directly adjacent to the lower laterals and thus improve the subsequent driving process. After the lower laterals have been opened and oil begins to flow in the lower laterals, steam may thereafter be injected into the vertical wells to drive the oil toward the lower laterals.

Soaking the formation about the lower laterals prior to establishing the driving process, as described above, may be beneficial in most applications. If a high viscosity oil is to be effectively driven, it may be desirable to establish many flow paths between the upper portion of formation and the lower recovery laterals prior to the driving cycle.

If steam is to be used as the injection fluid, the efficiency of the downward driving process may be increased by first injecting steam in the lower set of laterals 21-28. For this initial steam soak procedure, valve 60 may be closed and valve 62 opened allowing steam from the generator 56 to enter the formation through perforations 54 in each of the laterals 21-28. As the lower portion of a formation 16 is being soaked, viscous fingering and gravity override will readily occur since the injected fluid is lighter than the oil, and is being introduced in the lower portion of the formation. As viscous fingering and gravity override occur, heated communication paths will be established between the lower set of laterals and the upper portion of the formation. The pre-driving soak operation is utilized for reducing the time and pressure required for an effective driving operation and for initially recovering oil. The effects of viscous fingering and gravity override at this soaking stage are therefore not detrimental but are rather useful to the recovery operation. Thus, the formation may be subjected to one or more steam soak cycles from steam supplied through a lower set of laterals prior to the driving operation, wherein steam is injected into the lower laterals, the laterals are stopped off or shut in, and the laterals are opened for recovery of oil as a result of the soaking process. When the re-

peated soaking of the lower laterals results in steam fingering to the top of the formation 16, the soaking process may be discontinued and steam thereafter injected into the vertical wells 31-38 for driving the oil downward while recovering oil from the lower set of laterals.

An illustrative method of recovering oil according to the concepts of the present invention will now be discussed in further detail. After both the horizontal laterals and vertical wells have been drilled, steam from the generator 56 may be injected into the formation 16 from each of the lower laterals 21-28 for the soaking operation previously described. After steam migrates to the top of the formation, further steam injection in the lower laterals may be terminated, and the oil in the vicinity of the lower laterals should be sufficiently heated to a desired low viscosity. The desired time for this soaking operation will vary with formation characteristics, and the soaking operation may typically be complete in a period of approximately 120 days. The quantity of steam, expressed in equivalent volume of water, that is injected into the formation for the soaking operation may be between 5% to 10% of the pore volume of that portion of the formation affected by the soaking operation.

After the soaking operation is complete, valves 66 may be closed and valves 70 opened for the recovery of oil. Either simultaneously or shortly thereafter, valve 60 may be opened so that steam will be injected into the formation from each of the vertical wells while oil is being recovered from the horizontal laterals. As previously discussed, steam may be initially injected into the formation through perforations in that portion of each of the vertical wells within the formation. Steam injection at different levels within the formation is possible, as explained below. As the steam drive operation continues, formation receptivity to steam increases and a higher percentage of steam will therefore be injected into the upper portion of the formation. For instance, when the steam/oil interface approaches that depicted in FIG. 3, approximately 80% of this steam may be injected into the formation from the upper half of the perforated vertical wells. Also, interstitial water may tend to accumulate in the location adjacent the lower portion of each of the vertical wells, which will further reduce steam injection in the lower perforations 40.

Since the principal recovery mechanism according to the present invention is vertical steam drive, the above characteristics do not detract from the effectiveness of the operation. In fact, once the formation is heated and "hot flow paths" are established in the formation, it is desirable that steam be injected into the upper portion of the formation to drive the oil downward. If desired, the location of steam injection from each vertical well may be controlled by a variety of procedures. Sand or cement may be pumped into the vertical wells to plug off the lower portions. Alternatively, standard packers or bridge plugs may be used to regulate the steam injection location from each of the perforated vertical wells.

In FIG. 2, the location of each of the vertical wells is depicted according to one embodiment of the present invention. Each of the vertical wells may be evenly spaced horizontally between respective recovery laterals and positioned toward the periphery of the blanketed zone. The vertical wells may therefore lie in a circular or oval configuration within the blanketed area defined by the horizontal recovery laterals. Additional vertical wells may be provided, although it is a feature

of this invention to provide an equal number of vertical wells and horizontal laterals, and to space each of the vertical wells between respective horizontal laterals.

The formation 16 depicted in FIG. 3 is divided vertically into five imaginary zones K1-K5 of equal thickness. In the cross-sectional view depicted, K5 includes lens 84, K3 is shown to contain tilted lens 86, and K2 has lenses 88 and 90. Although each of these lenses may be impregnable to fluid flow, the efficiency of the recovery operation is not seriously altered since the vertical driving technique pushes the oil around these lenses. Recovery laterals lie within the lower zone K1 and may be 5 feet or less above the rock layer 17.

Although each of the vertical wells may terminate in any of the zones K1-K5, it is a feature of this invention that the vertical wells extend into the lower half or lower portion of the formation, and therefore terminate in zones K1, K2, or K3. It is desirable to minimize the likelihood of steam short circuiting between the lower portions of the vertical wells and one of the recovery laterals. For this reason, the vertical wells preferably terminate at a location above the horizontal laterals, and may terminate above zone K1. The lower the vertical wells extend, however, the greater the length of perforated pipe within the formation to maximize initial injection rates, and the injected steam is better able to maintain and reduce the viscosity of the oil in the lower portions of the formation.

Injection through the vertical wells 31-38 while recovering oil from the horizontal laterals 21-28 may continue until a high percentage of the oil is efficiently driven from the formation. As noted earlier, the steam/oil interface at the location of each of the vertical wells will generally widen as the process continues, but the principal driving force remains the vertical driving mechanism of the increasing gas cap. Thus, the ceiling of the steam/oil interface is descending while steam is injected into the vertical wells to drive the oil downward to the recovery laterals.

As the dynamic driving process continues, and especially when the steam/oil ceiling is in the lower portions of the formation, a possibility exists that steam may short circuit or finger through to one of the recovery laterals. Referring to FIG. 3, for example, it may be seen that steam has started to break through the normal steam/oil interface at 92, which may be attributable to any number of formation characteristics. As the vertical driving process continues, the degree of fingering at 92 may increase to the extent that the tip of the finger extends to recovery lateral 26, so that steam "breaks through" to the recovery lateral.

It is within the concept of this invention to increase the efficiency of the vertical driving operation by healing steam breakthroughs, and thereby minimizing the detrimental effects of steam fingering that are possible during the latter stages of the driving operation. Healing of steam breakthroughs may be accomplished by reducing or choking back the recovery from the specific lateral receiving steam. For instance, if steam does break through to lateral 26, recovery may be reduced by totally or partially closing valve 70 for lateral 26. Partially closing valve 70 for this lateral would have the effect of increasing the pressure in the area of the formation adjacent lateral 26. The effect will be a smaller pressure differential than previously existed, which will cause the steam breakthrough path to tend to seal or heal with viscous oil and/or water. After a period of time, valve 70 for lateral 26 may be further opened, and

the oil may be recovered at a normal rate without steam breakthrough.

It should be noted that this healing of steam fingering, as described above, is unique to vertical drive operations and cannot be efficiently accomplished in a horizontal drive operation. During horizontal drive, steam breakthrough to vertical recovery wells generally occurs in the upper portion of the formation because of the affects of gravity override. Choking back the vertical recovery well is possible, of course, but this will not tend to heal the path of this steam fingering. In the vertical drive operations described above, however, steam fingering is not likely to occur until the latter stages of the recovery operation and the steam fingering path is generally at a downward angle to the recovery well. Thus, choking back on the lateral recovery well allows viscous oil and water to descend due to gravity and steam pressure, so that the downward extending fingering path may be allowed to seal or heal.

This healing operation is a significant feature of present invention, since the life of the driving operation may be effectively prolonged. Using horizontal drive techniques, steam may typically break through to a recovery well after one year of driving operation. Since healing of the breakthrough is not generally practical, the driving operation must then be terminated. In the vertical driving operation described, steam breakthrough is less likely to occur. Equally significant, the breakthrough may be efficiently healed so that the driving operation may be prolonged. Thus, vertical steam drive with the above healing procedure may allow the driving operation to continually proceed for approximately five years, until a high percentage of the oil is efficiently driven from the formation.

Other methods of healing the steam fingering previously described are possible, and will now be discussed. Steam may be continually injected into the vertical wells 21-28 until a significant amount of condensate or steam has been recovered from one of the lower laterals 31-38. At this point, further injection of steam may not be economical, since little if any further oil will be recovered from the lower lateral receiving steam. If individual vertical recovery lines are used to connect each lateral to the recovery tank 74, it is possible to monitor the fluid being recovered at the surface 14 from each lower lateral. In this manner, it may be desirable to discontinue the injection of steam into vertical wells which are adjacent the lower lateral in which steam or condensate is being recovered, while continuing to inject steam into the other vertical wells as long as oil is being produced from their respective adjacent lower laterals. If the recovered oil is either being forwarded to a subsurface manifold 72 or is being taken from a common sump hole 18, the monitoring of the recovered fluid from the individual lower laterals may be accomplished before that fluid is intermingled with fluid from the other lower laterals.

Referring again to FIG. 2, the following is an example of the monitoring procedure described above. Steam may be initially injected into the eight vertical wells 21-28, as described above. Continued injection of the steam will drive the oil in the formation to the lower laterals. Once steam or condensate has been recovered from one of the lower laterals, e.g., lateral 21, steam may continue to be injected into the vertical wells 33-38, while steam is not injected through the vertical wells 31 and 32. Thus, oil recovery will continue from the lower laterals 22-28, but steam production from the

lower lateral 21 would be effectively discontinued. Oil recovery may thereafter continue from lateral 21 by gravity drainage.

An alternate procedure that may be used when steam or condensate is recovered in one of the plurality of lower laterals is to inject cold water into the lower lateral while continuing steam injection into all the vertical wells. Referring to the example described immediately above, if steam or condensate is being recovered from the lower lateral 21, cold water may be injected into lower lateral 21 while continuing to inject steam in either upper laterals 33-38 or all the upper laterals 31-38. The introduction of cold water into the lower lateral 21 effectively terminates the recovery of any fluid from the lower lateral, and thus the steam subsequently injected into the formation would be effectively used to produce oil from the laterals 22-28. The injected cold water scavenges heat from the formation adjacent lateral 21, generating some steam in situ, which, together with hot water, displaces additional oil to the other laterals.

The method of recovering oil described above may be characterized as embodying a dynamic vertical drive technique, since fluid is injected into the vertical wells as oil is recovered from horizontal laterals and the driving force is primarily vertically downward. Although a dynamic vertical drive may be preferred because of the reduced time required to efficiently recover a high percentage of oil, it is within the concept of this invention to employ a modified driving technique herein described. The modified driving technique utilizes "drive" principles since fluid is injected at one place in the formation and oil is driven under pressure to recovery from another location. The modified drive technique differs from the dynamic drive operation, however, in that fluid is not injected while oil is recovered.

According to the modified drive technique of this invention, the recovery laterals 21-28 may be initially soaked, in the manner previously described. Thereafter, steam may be injected into the formation through the perforations 40 provided in each of the vertical injection wells, while both valves 66 and 70 for each lateral are closed and the laterals are thus shut in. The desired time of steam injection will necessarily vary with formation characteristics. Since the recovery laterals are shut in and steam breakthrough is not possible at this time, however, the injection period may be quite short, e.g., 30 days.

Steam injection into the formation from each of the vertical wells may then be terminated or substantially reduced, and each of the recovery laterals 21-28 opened for the recovery of oil. Once the rate of oil recovery drops below an acceptable value, the recovery laterals may again be shut in (or substantially restricted), and steam re-injected into the vertical wells. The second injection period may then be terminated, and oil again recovered from the laterals. The sequence may be continually repeated until the oil is driven from the formation.

It may be seen that oil is recovered in the modified drive operation in a manner similar to the dynamic drive operation, except that the recovery of oil may take longer since oil is not recovered when steam is injected. Except for the initial soak operation, which is optional, oil is always driven toward a recovery lateral. Thus, energy is not wasted moving oil back and forth in the formation, as is common to soak techniques.

The above modified drive technique similarly is not burdened by the detrimental effects of fingering and gravity override. A steam/oil interface thus may be established in a manner similar to the dynamic vertical drive technique. A gas cap may be formed below the rock layer 15, and steam pressure exerts a downward force driving oil toward the recovery laterals. Also, the above described "healing" of steam fingering is possible in conjunction with the modified vertical driving technique. For example, the recovery lateral receiving steam may be choked back during the recovery cycle, while the remaining laterals are fully open to receive oil.

The oil recovery efficiency of the present invention may be improved by injecting an inert gas into the formation after steam injection and steam drive has been accomplished. Once the oil in the formation is sufficiently heated to a desired reduced viscosity and the steam/oil interface has been adequately established, inert gas injection may accomplish the same vertical driving force as steam injection. The net oil recovery efficiency should increase, however, since the production of steam requires much more energy than a similar volume of either cold or hot noncondensable gas. Injected gas will rise to the top of the formation to drive the oil downward, and will not tend to condense if the formation temperature declines. A suitable noncondensable gas for either a dynamic vertical driving operation or a modified vertical driving operation after steam injection is either nitrogen or stack gas.

Another technique for further improving the efficiency of the oil recovery operation includes the injection of cold water into the formation through the vertical wells after the formation is sufficiently heated by steam and the steam/oil interface or ceiling is driven vertically through the formation.

Water is customarily injected into a formation during conventional horizontal drive operations after steam injection to scavenge heat from the formation. The cold water is typically injected at the maximum possible rate to provide ample mechanical energy to displace the oil at high rates.

According to the present invention, which utilizes vertical drive techniques, cold water may be injected after steam injection, but cold water injection preferably occurs at less than the maximum possible injection rates. For instance, for the approximately 25 acres blanketed by the laterals depicted in FIG. 2, cold water may be injected from the vertical wells at a rate of approximately 200-400 barrels of water per day per injection well, which may be 10 to 20% of the maximum rate of injectivity. When water is injected into the formation at this lower rate, heat from the formation may be effectively used to create steam in situ. The additional creation of steam increases the gas cap volume which is beneficial to the vertical driving techniques disclosed herein. In a vertical drive technique, this low injection rate of cold water prevents the collapse (condensation) of the steam previously existing in the formation and thereby increases the driving pressure of the operation.

An alternate method of practicing vertical steam drive in conjunction with cold water injection will now be discussed. Steam may be injected into the formation from each of the vertical wells 31-38 while oil is recovered from laterals 21-28. After the steam cap has filled the upper fifth of the formation, e.g. zone K5 in FIG. 3, steam injection in zone K5 is terminated, and cold water is injected into the wells 31-38 to result in the provision

of steam below zone K5. In response to cold water injection into the wells 31-38, steam is formed in situ and thus injected into zone K4. Once the steam/oil ceiling drops below zone K4 as vertical drive continues, injection of steam into zone K4 is terminated, and cold water is injected into the wells 31-38 to be converted in situ into steam to lower the steam cap below zone K4 simultaneous with or immediately prior to injection of steam into the wells 31-38 which then rises to zone K3. In this manner, sequential layer to layer of steam injection, followed by water injection exploiting the above layer, may be effectively practiced. The vertical drive concept of the invention is thus utilized, and the injection of cold water minimizes the fuel cost for the recovery operation, and thus increases the net oil recovery rate.

In the embodiments of this invention described above, the primary mechanism for oil recovery is downward vertical drive; injected fluid rises to the top of the formation forming a gas cap which drives the oil downward to recovery laterals. It is also within the concept of this invention to drive vertically upward, and the conventional vertical bore holes herein described may terminate near the bottom of the formation if upward drive is desired.

A portion of an apparatus embodying the upward vertical drive concepts of this invention is depicted in FIG. 4. A formation 16 is shown to be bounded by upper rock layer 15 and a lower rock layer 17. The apparatus above rock layer 15 is not depicted, but may be similar to that shown in FIG. 1, and will be readily understood.

The mine shaft 110 and upper work chamber 112 may be constructed in the manner previously described. A plurality of recovery laterals extend from the formation and blanket an area from which oil is to be recovered. Although only two laterals 114 and 116 are depicted in FIG. 4, eight laterals may extend from the work chamber 112 in a rectangular pattern as depicted in FIG. 2. Any plurality of laterals may be provided, however, which will lie in a generally horizontal plane and blanket a desired area. The work chamber 112 may be constructed either below the upper rock layer 15 or within the rock layer 15 and the formation 16. The laterals 114 and 116 preferably are immediately below the rock layer 15, and may typically be 5 feet or less from the formation 16/rock layer 15 interface.

Vertical wells 120, 122, 124 and 126 are depicted in FIG. 4, and each vertical well may be constructed in a manner similar to vertical well 37, with perforations 128 in that portion of each vertical well within the oil bearing formation 16. Although only four vertical wells are depicted in FIG. 4, it is to be understood that the number and position of the vertical wells will depend on the number of horizontal laterals, and that the vertical wells are preferably positioned between adjacent laterals and toward the periphery of the blanketed area, as previously described. For instance, if the laterals in FIG. 3 blanket an area as depicted in FIG. 2, eight vertical wells may similarly be provided, with the vertical wells positioned as shown in FIG. 2. Each of the vertical wells preferably terminates in the bottom half of the formation, and may terminate several feet above the rock layer 17.

In FIG. 4, it may be seen that each of the laterals 114 and 116 is provided with a respective steam injection line 130 and 132. Valves 134 may be located within the work chamber 112 or may be placed at the surface, and

may regulate steam injection to each of the laterals. Oil may be recovered from laterals 114 and 116 by respective recovery lines 136 and 138. Similarly, valves 140 may be located at the surface or in the work chamber to control recovery from each lateral. Although only two laterals are depicted in FIG. 4, it is to be understood that individual injection lines, recovery lines, and control valves may be provided for each recovery lateral.

One method of recovering oil according to the concepts of this invention will now be described for the apparatus depicted in FIG. 4. If desired, steam may be injected into each of the laterals 114 and 116 to soak the area adjacent each lateral. Thereafter, water may be injected into each of the vertical wells, and water will enter the formation through perforations 128 in that portion of each of the vertical wells within the oil bearing formation. At the temperature and pressure within the formation in FIG. 4, it may be assumed that water is more dense than the oil within the formation. Water will, therefore, migrate downward and form a substantially horizontal bed adjacent rock layer 17. Further injection of water will create a sufficient pressure force to drive the oil upward toward the recovery laterals. In this manner, oil may be efficiently recovered by an upward drive technique.

As the vertical drive operation progresses, the injected water/oil interface may proceed through the formation in the manner previously described, except that the interface will be flipped. In other words, the oil water/oil interface during the driving operation described above may resemble a plurality of cones with the apex of the cones near the top of the formation, and an increasingly thick substantially horizontal and continuous bed of water above rock layer 17. The vertical wells may be perforated for the entire portion within the oil bearing formation, and a limited amount of horizontal drive may occur, although the principal drive mechanism will be an upward vertical driving force.

A dynamic upward vertical drive is preferably utilized to recover oil for the embodiment depicted in FIG. 4, although a modified vertical drive procedure is possible. Since the injection of water is heavier than the oil within the formation, problems associated with gravity override and steam fingering are minimized, if not eliminated. Once cold water breaks through to one of the upper recovery laterals, that lateral may be shut in, in the manner previously described for the lower laterals, so that the drive operation may continue for the other upper laterals.

Although cold water has been described as the injected fluid, many hot or cold liquids could be utilized for the upward vertical drive technique which have a density greater than the oil within the formation. Since upward vertical drive is desired, injection of an inert gas after fluid injection may not be practical.

One significant advantage of the apparatus depicted in FIG. 4 is that the mine shaft need not extend through the oil bearing formation. Also, a cold liquid may be injected into the formation for the driving mechanism, which will substantially reduce equipment and operational costs. The vertical wells need not be fully perforated within the oil bearing formation, and may either be partially perforated or merely inject fluid into the formation from the end of the vertical wells. If the vertical wells are fully perforated, however, cold water may be injected at higher rates, and a minimal amount of horizontal drive will push the oil closer to the recovery laterals.

Although this invention is principally described with steam or water as the injection fluid, both heated and unheated fluids may be used as a driving force within the concept of this invention. For example, water, solvents, gas oil, distillate, LPG, and naphtha, or a combination of liquids and gases may be utilized as a driving fluid according to the present invention. Examples of gases that may be utilized in this invention are air, oxygen, hydrogen, carbon dioxide, inert gas, stack gas, steam, anhydrous ammonia, natural gas, ethane, propane, and butane. Also, although no additives must be combined with the fluid to be injected, the addition of additives may enhance the recovery process. Less heat is lost through condensation, and the average temperature of the formation is raised at a faster rate than in the prior art. Thus, the increased injection rates yield higher production rates, which improve the economics of the recovery operation.

The recovery of oil when utilizing vertical drive, as described according to this invention, may be further enhanced by reducing the pressure at the recovery laterals to a sub-atmospheric value while connecting the recovery laterals to suction-type pumps. In this manner, oil recovery may be enhanced regardless of whether the vertical drive is propagated by in situ combustion, steam injection, solvent injection, gas injection, or injection of any number of fluids commonly used to enhance the driving operation.

The present invention employs a vertical driving concept with oil recovery from a plurality of substantially horizontal laterals. In both the dynamic vertical drive technique and the modified vertical drive technique, oil is being continually driven toward the recovery laterals, and energy is not wasted moving oil back and forth within the formation. Nevertheless, an initial steam soak operation may be performed as described herein. Also, it may be beneficial to periodically "purge" the recovery lines for a short period by injecting steam through the laterals, although the recovery mechanism remains that of vertical steam drive.

The fluid injected into the conventional vertical wells according to the present invention serves to establish a uniform, substantially horizontal blanket to be driven vertically through the formation. The recovery laterals are generally positioned at a substantially horizontal plane, which may be inclined to conform to the inclination of the adjacent barrier layer, so that the formation may be effectively swept of oil. Some deviation of the laterals is expected, and in that sense the laterals may not lie precisely in flat planes. Further, the laterals typically lie in relatively thin discs approximately 5 feet thick, and these discs or "planes" may be inclined slightly to conform to the barrier layers.

It may also be seen that the present invention may be profitably employed by installing a plurality of vertical mine shafts and laterals, as described herein. Also, by operating such multiple installations in a simultaneous manner, an entire field may be drained in a systematic manner.

It may be that two or more oil bearing formations exist at different elevations. In such a case, it is within the concept of this invention that a vertical mine shaft may be employed, and the vertical wells and recovery laterals may extend from the mine shaft into each of the oil bearing formations.

As herein described, the techniques of the present invention are principally directed to recovering relatively heavy oils. However, it should be noted that

these techniques are not limited to heavy oils only, but can be used with substantial effect in recovering hydrocarbons of various weights and gravities.

Other alternate forms of the present invention will suggest themselves for a consideration of the apparatus and practices hereinbefore described. Accordingly, it should be clearly understood that the systems and techniques depicted in the accompanying drawings, and described in the foregoing explanation, are intended as exemplary embodiments of my invention, and not as limitations thereto.

What is claimed is:

1. A method of recovering oil from a subsurface earth formation in which formation a steam cap can form comprising:

establishing a shaft hole extending from the surface to said subsurface earth formation;

drilling a first plurality of boreholes radially from said shaft hole in a substantially horizontal plane within a lower portion of said formation, said first plurality of boreholes defining a blanketed zone;

drilling a second plurality of boreholes within the blanketed zone substantially vertically from said surface into said formation, said second plurality of boreholes extending to a depth above said first plurality of boreholes;

heating oil in said formation by injecting a heating fluid into one of said plurality of boreholes;

injecting steam into said second plurality of boreholes to form a gas cap; and

thereafter discontinuing injection of steam through said plurality of boreholes and injecting water such that said water is converted to steam to further provide for drive of oil by said gas cap towards said first plurality of boreholes.

2. The method according to claim 1 wherein the step of injecting water comprises injecting at a rate which is a fraction of the rate of injectivity of said formation.

3. The method according to claim 2 wherein the step of injecting water comprises injecting at the rate of 10-20% of the maximum rate of injection and wherein said step is performed subsequent to recovery of oil from said formation.

4. The method according to claim 1 wherein the step of injecting water following injecting steam comprises performing a plurality of cycles of injecting steam through said second plurality of boreholes, discontinuing injecting steam and then injecting water.

5. The method according to either of claims 3 or 4 wherein the step of injecting steam into said second plurality of boreholes further comprises the step of injecting non condensable gas in addition to injecting steam.

6. The method according to either of claims 3 or 4 wherein the step of injecting fluid into one of said first or second plurality of boreholes comprises the step of injecting steam into said first plurality of boreholes, and performing a soaking operation prior to injection of steam into said second plurality of boreholes.

7. The method according to claim 6 wherein the step of injecting heating fluid comprises injecting steam.

8. The method according to claim 7 further comprising the steps of monitoring oil recovery from each of said first plurality of boreholes, and regulating injection of steam through selected ones of said second plurality of boreholes in response to oil recovery from each of said first plurality of boreholes.

9. The method according to claim 7 wherein the step of drilling said second plurality of boreholes comprises spacing each borehole of said second plurality of boreholes equally in a horizontal direction between two of said boreholes within said first plurality of boreholes.

10. The method according to claim 9 wherein the step of drilling said second plurality of boreholes further comprises spacing each of borehole in said second plurality of boreholes 60 to 95% of the distance from the center of said shaft hole to the extremity of the blanketed zone.

11. The method according to claim 10 wherein the step of providing said first plurality of boreholes comprises providing eight radially extending boreholes and wherein the step of providing said second plurality of boreholes comprises providing eight boreholes terminating twenty feet vertically from said first plurality of boreholes and wherein each of said second plurality of boreholes exposes one hundred feet of perforations in a vertical direction to said formation.

12. In a method of recovering oil from a subsurface earth formation in which formation a steam cap can form comprising the steps of establishing a shaft hole extending from the surface to said subsurface earth formation; drilling a first plurality of boreholes radially from said shaft hole in a substantially horizontal plane within a lower portion of said formation; drilling a secondary plurality of boreholes substantially vertically from said surface into said formation, said second plurality of boreholes extending to a depth above said first plurality of boreholes; heating oil in said formation by injecting a heating fluid into one of said plurality of boreholes; the improvement comprising:

injecting steam into said second plurality of boreholes to form a gas cap; for causing production from said first plurality of boreholes and thereafter discontinuing injection of steam through said plurality of boreholes and injecting water such that said water is converted to further provide for drive of oil by said gas cap.

13. The method according to claim 12 wherein the step of injecting water comprises injecting at a rate which is a fraction of the rate of injectivity of said formation.

14. The method according to claim 13 wherein the step of injecting water comprises injection at the rate of 10-20% of the maximum rate of injection and wherein said step is performed subsequent to recovery of oil from said formation.

15. The method according to claim 14 wherein the step of injecting water following injecting steam comprises performing a plurality of cycles of injecting steam through said second plurality of boreholes, discontinuing injecting steam and then injecting water.

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Alberta OIL SANDS

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Carlson [45] Mar. 13, 1984

4,436,153

Mar. 13, 1984

[54] IN-SITU COMBUSTION METHOD FOR
CONTROLLED THERMAL LINKING OF
WELLS

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[51] Int. Cl.³ E21B 43/243[52] U.S. Cl. 166/260; 166/50;
166/245; 166/259; 166/261[58] Field of Search 166/256-261,
166/50, 59, 251, 245

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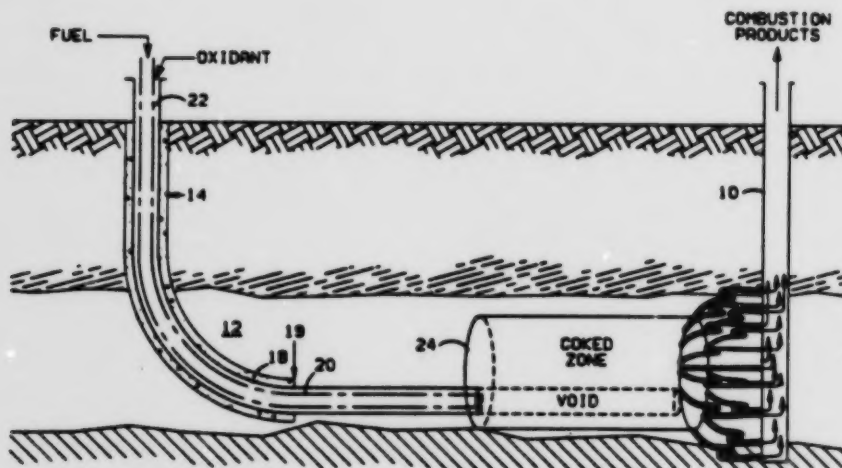
Primary Examiner—Stephen J. Novosad

Attorney, Agent, or Firm—Scott H. Brown; Fred E. Hook

[57] ABSTRACT

A method of controlled thermal linking of an injection well and a production well, both penetrating an underground formation, accomplished by injecting oxidant into the annulus of the injection well and fuel into the tubing of an injection well in stoichiometric proportions, and initiating a combustion zone at the production well which propagates along a predictable path in the formation which is a deviated or horizontal portion of the injection well.

5 Claims, 3 Drawing Figures



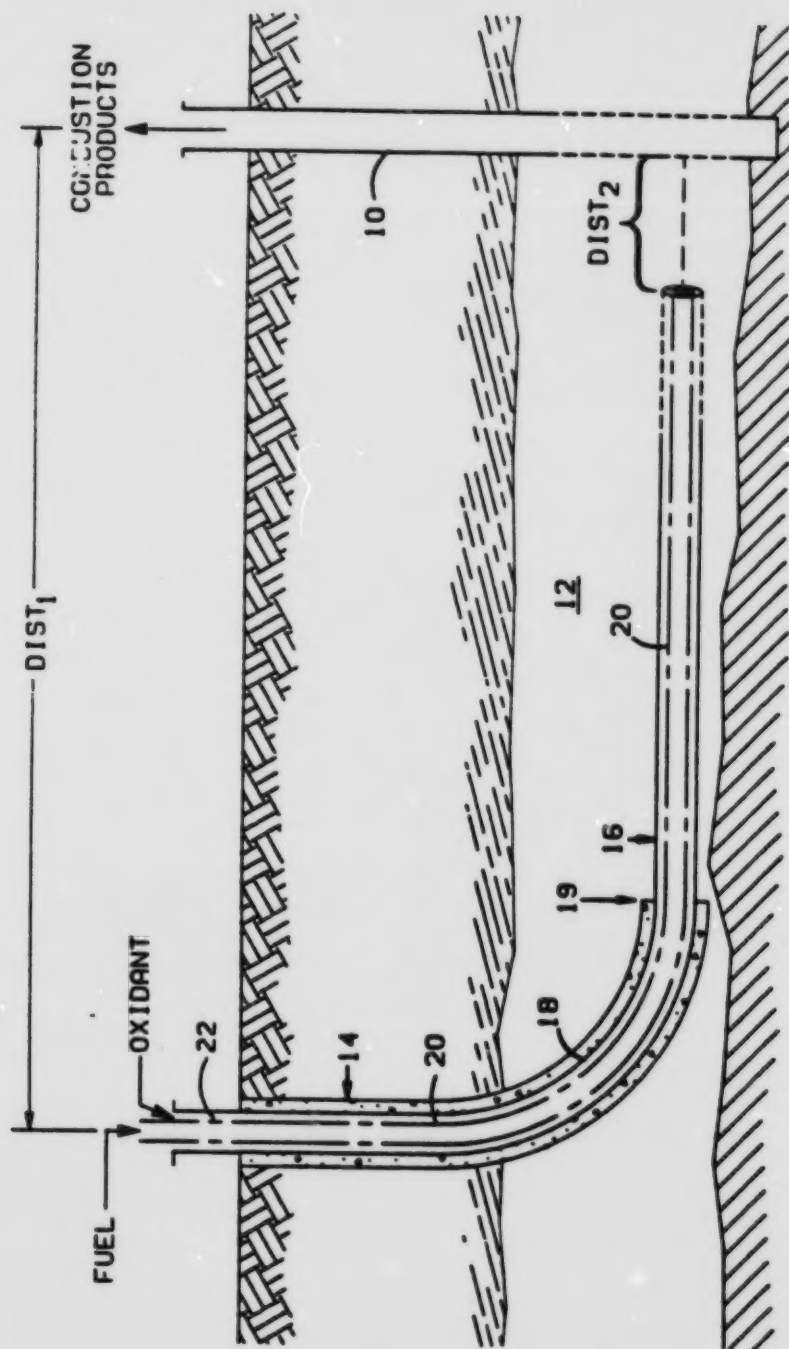


FIG. 1

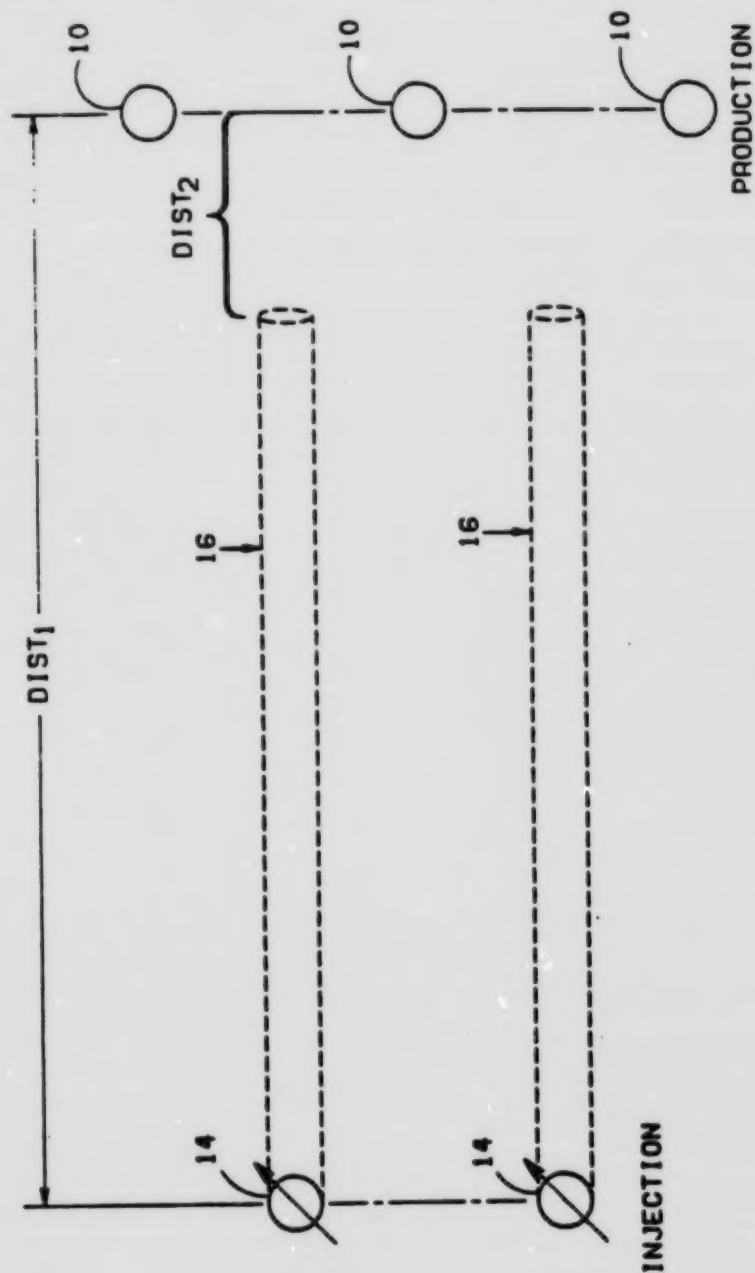


FIG. 2

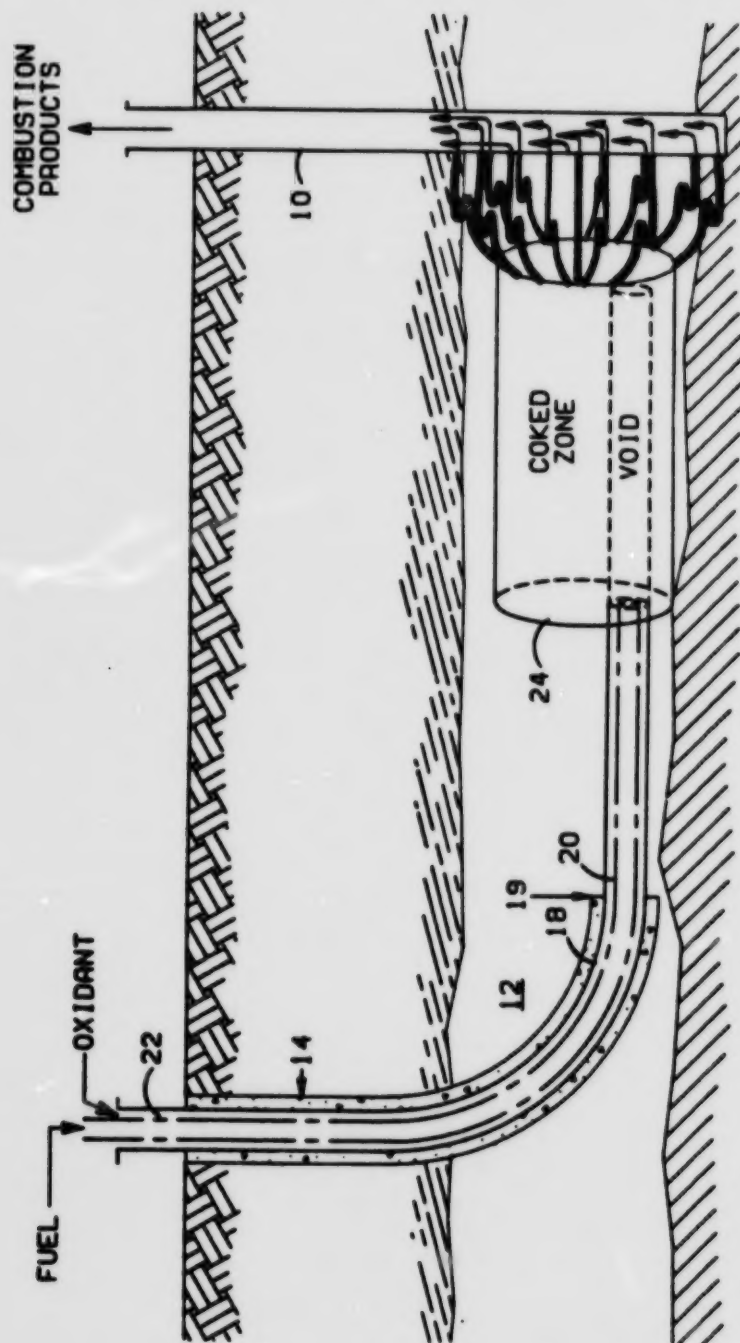


FIG. 3

IN-SITU COMBUSTION METHOD FOR CONTROLLED THERMAL LINKING OF WELLS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a novel method for in-situ conversion of hydrocarbon-bearing material and, more particularly, to such a method which allows for the controlled thermal linking of an injection well and a production well.

2. Setting of the Invention

In a practical sense, in-situ combustion methods to recover hydrocarbons from coal, tar sands or oil shale from underground formations have some control problems. Once a combustion zone has been initiated, the temperatures reached within the zone, the rate of travel and the exact direction of the zone may be difficult to control.

In a reverse combustion method to convert hydrocarbons, an oxygen, air or oxygen-containing gas or mixture thereof is introduced through an injection well and a combustion zone is established at a production well which moves toward the oxygen source at an injection well. A disadvantage of reverse combustion is that the heat losses to the formation may cause the reverse combustion zone progress to stall and then change into a forward mode, which may greatly reduce the amount of hydrocarbons recovered. The combustion zone will stop progressing against the flow of oxygen-containing gas and change to a forward mode and progress back towards the production well. Another disadvantage of reverse combustion is that a premature forward combustion mode can result from spontaneous ignition caused by the low temperature injected oxygen.

Reverse combustion suffers from another disadvantage, in that the procedure requires sufficient flux of the injected fluid. Flux can be defined as the volume of injected fluid per unit of time, per unit of area through which the fluid flows. There are two obstacles to the generation of this flux. First, the bitumen deposits are typically shallow so that the injection pressure and therefore the flux is limited. Exceeding this pressure limitation causes unnatural parting of the formation and subsequent loss of control. Secondly, the most desirable bitumen deposits, from an economic standpoint, are those containing the highest bitumen saturation. Unfortunately, the higher the bitumen saturation is, the lower the effective permeability to injected gas. Since the flux of the injected fluid is dependent on this gas permeability, it is therefore inversely proportional to the bitumen saturation. It can be seen that there is a need for a controlled process of in-situ combustion.

SUMMARY

The present invention provides a novel method contemplated to overcome the foregoing disadvantages. Herein, it is disclosed a method of controlling an in situ combustion process which comprises injecting oxidant and fuel into components of the injection well in stoichiometric proportions. Thereafter, a combustion zone is initiated at the production well which propagates towards the injection well along the path of a lower portion of the injection well. The injection of the oxidant and fuel provide combustion control, as well as optionally water.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a cross sectional view of an injection well and a production well completed in accordance with the present invention.

FIG. 2 is a plan view of an arrangement of a plurality of injection and completion wells arranged in accordance with the present invention.

FIG. 3 is a cross sectional view of the thermal linking method.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides a novel in-situ conversion method that utilizes a reverse combustion zone to thermally link an injection well and a production well and provides for better combustion control.

Referring to the drawings in detail, reference character 10 generally indicates a production well completed in any suitable manner for the production of hydrocarbons as is well known in the art. The production well 10 penetrates a subterranean hydrocarbon bearing formation 12 and is completed and perforated in any known manner. The formation 12 can either be a coal seam or a seam of bitumen-saturated material, such as tar sands, or kerogen-saturated material, such as oil shale. The present discussion is directed towards use of the method in conversion of tar sands.

An injection well 14 is spaced at the surface a certain distance $DIST_1$ from the production well 10. $DIST_1$ is variable and is dictated by field experience with the present method and should be close enough to allow injected gases to be conveyed to the combustion zone. The injection well 14 penetrates the formation 12, and a lower portion 16 thereof is deviated or directionally drilled in any known manner so as to be landed adjacent the production well 10. The lower portion 16 of the injection well 14 is completed so as to lie in a plane essentially horizontal to the formation 12 for maximum conversion efficiency. Also, if possible, the lower portion 16 would be horizontally spaced adjacent the bottom boundary of the formation 12, as shown in FIG. 1, in order to efficiently use gravitational forces during the conversion process.

The injection well 14 includes a string of casing 18 which is cemented only from the point of deviation 19 to the surface. The casing 18 is preferably metallic and all or a portion thereof is perforated as is well known in the art. Disposed within the casing 18 is an internal tubing 20 which can be the same or a different material than the casing 18. The tubing 20 is installed for the entire length of the wellbore, even if the injection well 14 is not cased the full length.

A certain distance $DIST_2$ represents the distance between the end of the tubing 20 and a plane passing through the vertical axis of the production well 10 at the formation 12. The properties of the formation 12 and field experience will determine how great $DIST_2$ should be, but the guiding principle would be that it would be short enough to obtain adequate flux (volume of injected fluid per unit of time per unit of area through which the fluid flows) to initiate and maintain a reverse combustion zone between the production well 10 and the end of the injection well 14.

In order to adequately and efficiently produce hydrocarbons and other produced gases from the formation 12, a series of injection wells 14 and production wells 10 can be spaced in a parallel arrangement, as shown in

FIG. 2. The wells may also be arranged in any other pattern, such as a five-spot, if desired.

To initiate the process, a flow path between the end of the tubing 20 and the production well 10 is established. If adequate permeability to injected fluids does not exist in this area, such permeability may be induced by any known means, such as by acidizing or fracturing. Oxidant, such as oxygen, air or oxygen-containing, non-combustible gas, is injected down the annulus 22 of the injection well 14 and fuel, such as propane, butane, or other gaseous or liquid hydrocarbons, is injected through the tubing 20. The fuel may be injected down the annulus 22 and the oxidant down the tubing 20. The fuel and the oxidant may be injected down any conventional annulus conveyance means, such as the wellbore or any annulus between casings or tubings disposed in the wellbore. The oxidant and fuel are injected in stoichiometric proportions for peak combustion efficiency into the formation 12. A reverse combustion zone is conventionally initiated adjacent the production well 10 which burns towards the flow of oxidant from the end of the tubing 20. The produced combustion products are withdrawn through the well 10 to the surface for use elsewhere. When the combustion zone reaches the end of the tubing 20, the progress of the zone will be retarded and the temperature will begin to rise since an adequate supply of fuel and oxygen are being supplied. The temperature will continue to rise until it is sufficient to either burn or melt the tubing 20 and/or casing 18 at the end of the injection well 14. Thereafter, the combustion zone progresses "upstream" along the deviated or lower portion 16 of the injection well 14 destroying the casing 18 (if present) and the tubing 20 as it proceeds and transferring heat to the formation 12. The rate of advancement of the zone is controlled by the amount of oxidant and fuel injected through the well 14. By this method, the temperature of the formation 12 adjacent to lower portion 16 will be elevated at every point along the path between the injection well 14 and the production well 10, and thus the wells are considered thermally linked, which permits better control of the combustion process as will be discussed more fully below.

The advantages of reverse combustion are realized near the production well 10 and continue as the combustion zone moves along the horizontal axis of the injection well 14. The end of the injection well 14 can be located as near the production well 10 as needed to improve the deliverability of injected fluids through the formation 12 to the production well 10. Clearly, the amount of air permeability required to establish the required flux for a reverse combustion zone becomes less if the end of the injection well 14 is located close to the production well 10, whereby $DIST_2$ would be quite small, i.e., 2-15 ft.

Different means of control can be designed into the process to achieve different peak temperatures for best conversion of hydrocarbons. The choice of casing thickness and casing type (e.g., steel, aluminum, etc.) are two such design parameters. Combinations such as steel casing and aluminum tubing are also possible.

If the combustion zone should progress too rapidly, the rates of oxidant/fuel injection may be varied and/or water may be injected either alternately with the oxidant-fuel or through an additional string of tubing (not shown). If desired, the additional string of tubing could have thermocouples installed therein instead of being used for water injections so that the progress of the burn could be monitored at the surface.

The present method preserves the inherent advantages of reverse combustion, such as (1) the hydrocarbons in the vicinity of the combustion front are cracked which yields a much upgraded product having a reduced viscosity and specific gravity; (2) the upstream hydrocarbons that are either mobile or become mobile are forced into a region of higher temperature where they are subsequently cracked and upgraded; (3) in situations where bitumen saturated sands are unconsolidated, consolidation occurs by the formation of coke around the burn area thus alleviating production problems caused by the sand; (4) some thermal stress is set up within the sand-coke matrix creating minute fractures that increase the ability to pass fluids therethrough; and (5) the removal of the viscous bitumen increases the relative permeability to the combustion vapors allowing them to pass more easily through the burned area. Further, none or little of the formation materials are consumed in this process to generate the heat required to convert the formation material.

With regard to tar sands, it may be desirable to leave the zone between the end of the tubing 20 and the production well 10 in a coke/consolidated state following the reverse combustion since it will tend to act as a filter to sand that may be freed when some type of production mechanism is later employed. Thus, production problems caused by sand would be alleviated. Also, this region could provide a direct channel for produced hydrocarbons to the production well 10 in the event that steam soaks will be later employed during the production phase. If there is still insufficient air permeability to initiate the reverse burn through the region, it could be artificially induced by existing methods. Due to the proximity of the injection well 14 and the production well 10, control of such an inducement would be enhanced.

The problem of low temperature oxidation in situ combustion is controlled by this method. Low temperature oxidation can only occur at the point where the oxidant mixes with the fuel. Since the injected or in place fuel is not mixed with the oxidant until it reaches the end of the injection well 14, this problem is eliminated upstream of the point of mixing. Downstream towards the production well from the point of deviation, low temperature oxidation can take place but should not present any difficulty with the anticipated close spacing between the production well 10 and the end of the injection well 14. Also, the explosive hazard by the use of the fuel and oxidant is minimized since the fuel and oxidant are mixed underground instead of at the surface as in the past, and no excess oxidant is injected because the oxidant and fuel are in stoichiometric proportions. Higher quality, less permeable bitumen sands can be used by this method due to the close spacing of the wells. The depth of the formation 12 becomes less critical by this method since lower pressures will suffice to establish the required flux for reverse combustion. Also, the surface well spacing is less critical than normal in in situ combustion layouts since a deviated hole is used for the injection well 14.

As the combustion zone moves in a reverse mode towards the injection well 14, the formation of the burn zone extending out from the production well 10, even if it is naturally unconsolidated, will become consolidated with coke as shown in FIG. 3. The coke results from the fact that the oxygen is fully consumed by reaction with either the lighter hydrocarbon ends cracked from the bitumen or with the injected fuel. As the combustion

zone moves through the formation 12, a coke cylinder 24 will be created coaxially with the essentially horizontal lower portion 16 of the injection well 14. The temperatures within the cylinder 24 will range from some maximum at the center to the ambient at some distance from the center. The flow capacity may be largest in the center of the cylinder 24 due in part to the void of the wellbore, but due also to the fact that the fluid where the temperatures were the highest would have been cracked or vaporized, and these vaporized lighter hydrocarbon ends and water would have been removed by displacement. The residual products would be deposited as coke surrounding the sand grains in the formation 12, but this coke would have a higher permeability than the original formation. As the temperature decreases radially outward from the axis of the injection well 14, the flow capacity of the cylinder 24 will decrease proportionately.

Once the combustion zone has moved as far upstream along the lower portion 16 as desired, the combustion zone can be changed to the forward mode by ceasing the injection of fuel and injecting only oxidant, water, or some combination of water and oxidant. Injecting only oxidant has both an advantage and a disadvantage. The advantage is that all of the coke will be consumed as the forward combustion zone progresses, leaving only the rock matrix. If the rock matrix is unconsolidated, as is the case for a large percentage of bitumen deposits, removal of the coke will leave the matrix unsupported, resulting in a fresh supply of bitumen saturated sand falling into the combustion zone area as the roof above the created void collapses. In this manner, a large cavern would be created behind the leading edge of the combustion zone. Clearly, it would be important to have the horizontal axis of the injection well 14 near the bottom of the formation 12. Since all the coke will be consumed in the process, the recovery of hydrocarbons vs. the amount of oxidant injected could reach a point of diminishing return. The cost of compressing the injected oxidant therefore may be large. To reduce these costs, water could be injected along with or alternately with the oxidant fuel with a possible detrimental effect of decreased roof collapse since all the coke will not be consumed in the process. This remaining coke will tend to bind the sand together, leaving it in a consolidated form, and thus prevent the roof from collapsing. Roof collapse could be beneficial from the standpoint of providing a fresh supply of fuel to the reaction zone, but could alternately produce the undesired effect of surface subsidence.

Regardless of the forward mode of operation, the coke cylinder 24 created during the reverse combustion will be the means by which combustion products will be transported to the production well 10. Injecting water would transfer heat more rapidly through this permeable channel than by the injection of oxidant alone; however, there would be a tendency to keep the channel at a higher temperature and, in general, keep it more conductive to the flow of products through it.

This process has been generally described in connection with tar sands but the process also can be used in in

situ coal gasification. A process which has gained considerable appeal in recent years with respect to the underground gasification of coal is called the "link vertical well process". It is a procedure which employs reverse combustion to establish a thermal link between the production and the injection well. Unfortunately, there is very little control over the path the reverse combustion zone follows. Once created, the carbonized zone surrounding the area swept by the combustion zone is then gasified in a forward mode, a void is created as the fuel is consumed in the forward mode, and the roof collapses into the void in a much larger area. It appears that the critical process is the creation of the thermal link along a known path. The creation of the thermal linking of wells along a known path is outlined within this invention.

Finally, this method could be applied to the in situ recovery of oil from oil shale. The oil shale could either be in the form of an artificially created rubble or in its native state. It is thought that the reverse burn would induce foliation of the shale, thus creating permeability through the shale during the linking process.

Whereas, the present invention has been described in particular relation to the drawings attached hereto, it should be understood that other and further modifications, apart from those shown or suggested herein, may be made within the scope and spirit of this invention.

I claim:

1. A method of underground conversion of hydrocarbon-bearing material disposed in a subterranean formation, the method being carried out between an injection well and a production well wherein a portion of the injection well is deviated toward the production well, comprising:

- initiating a combustion zone in the hydrocarbon-bearing material adjacent the production well;
- injecting an oxygen-containing gas and a combustible material through separate conveyance components of the injection well for mixing adjacent the end of the injection well;
- advancing the combustion zone through the formation from the production well to the injection well along the deviated portion of the injection well;
- and
- removing produced gases from the formation through the production well.

2. The method of claim 1 wherein the deviated portion of the injection well lies in approximately a parallel plane to the formation.

3. The method of claim 2 wherein the deviated portion of the injection well lies adjacent the lower boundary of the formation.

4. The method of claim 1 wherein the end of the injection well is landed immediately adjacent the production well.

5. The method of claim 1 wherein the advancement of the combustion zone is controlled by the injection of an aqueous liquid into at least one of the conveyance components of the injection well.

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[US Patent 4,381,124]



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(54) METHOD OF MINING AN OIL DEPOSIT

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METHOD OF MINING AN OIL DEPOSIT

The present invention relates to development of oil fields and, more particularly, it relates to a method of thermal-mining production of oil and can be used in the petroleum industry.

This invention can be used most efficiently in the development of oil fields characterized by highly viscous oils and fluid asphalts.

The invention can also be used for developing oil deposits with depleted reservoir energy.

At present, such deposits cannot be efficiently developed by the conventional method wherein oil production is accomplished with the aid of wells drilled from the ground surface. The resulting recovery is rather low.

Known in the art for developing oil fields with highly viscous oils and fluid asphalts is a mining method of oil production without lifting oil-bearing rock to the earth's surface (cf., A.Ya. Erens et al., *Shaktnaya razrabotka neftegoryastorozhdenii - The Mining of Oil Deposits*, Gosortekhnizdat Publishers, Moscow, 1955).

Said prior art method comprises driving, above the roof of the oil-bearing bed, a system of underground workings including fringe drifts with drill chambers. From the drill chambers, inclined and straight wells are drilled whose depth depends on the thickness of the oil-bearing bed and the distance from its roof to the drill chambers. After drilling the wells, oil is recovered therefrom by the flowing method and then by air-lift.



When employing the flowing method, oil is lifted from the oil-bearing bed through the wells to the drill chambers by reservoir pressure; in the case of air-lift, compressed air is injected via pipes placed in the well. From the drill chambers, oil is delivered via underground workings to central underground oil collectors from which it is pumped, following primary preparation and preheat, into tanks located on the ground surface.

This method helps increase the recovery by a factor of three and above as compared with the development by means of wells drilled from the earth's surface. However, the absolute value of recovery amounts to only about 4%.

Low recovery caused a need to employ mining methods of oil production, which provide for physically affecting an oil-bearing bed and the oil contained in the latter.

There is known in the art a method of thermal-mining production of oil involving the exposure of the bed to the effect of steam and heat (cf., V.N. Mishakov et al., *Opyt primeneniya teplovykh metodov pri shakhtnoi razrabotke nestrochdenii vysokoviskozikh neftei* - On the Use of Thermal Methods upon Mining Highly Viscous Oil Deposits, in *Neftianoye khozyaistvo* - Journal of Petroleum Industry, No. 10, 1974, pp. 31-35).

Said prior art method provides for driving above the oil-bearing bed a plurality of underground workings including shafts, shaft workings, drifts and drill chambers.

From the drill chambers located in the drifts, straight and inclined inlet and recovery wells are drilled. A heat carrier (steam) is supplied to the oil-bearing bed via inlet

wells, which drives oil from the inlet wells to the recovery wells. From the face of the recovery wells, oil is air-lifted to the drill chambers.

Said prior art method suffers from the sanding up of the recovery wells operating by the air-lift method and of the inlet wells. The recovery and inlet wells are clogged with sand from the bed.

In addition, the air-lift technique of oil production calls for equipping the wells with special pipes or devices for closing and opening the supply of air, when required, while considerable amounts of air are required for the delivery of liquid from the wells.

Said prior art method suffers from a low efficiency of the process of thermal-mining production of oil due to considerable heat losses through well walls into "barren", oil-free rock, as well as to large amount of drilling to be done in such rock.

According to still another prior art method of oil mining (cf., U.S. Patent No. 1,634,235), wells are drilled from underground workings located below the oil-bearing bed, and oil is extracted from shallow wells drilled from the bottom upwards. The underground workings are in this case arranged radially from the central shaft over the mining field area.

This prior art method provides for extraction of oil from the bed by gravity while the face zone of the bed is heated by way of supplying steam to the well face via pipes located in the wells.

Said method suffers from non-uniform arrangement of underground workings and wells over the mine field area. Mine

field portions adjoining the shaft are developed with the aid of a dense network of wells. Bed portions remote from the shaft are developed with the aid of a sparse network of wells. Such an arrangement of wells results in non-uniform mining of oil reserves.

There is further known a mining method of oil production (cf., U.S. Patent No. 1,506,727), according to which a vertical shaft is driven through the oil-bearing bed below which a drill chamber is arranged from which inclined and ascending wells are drilled in a radial direction.

A heat carrier (steam) is supplied to the oil-bearing bed through said wells via pipes having a diameter smaller than that of the well. Heated oil flows down into the drill chamber after which it is pumped up to the ground surface.

Although said prior art method makes for a simpler process of oil recovery and an increased recovery, the bed portion under development is limited by the possibilities of drilling the inclined wells or, to be more precise, by their length. Therefore, a limited bed portion is to be provided with an individual shaft built from the earth's surface. This affects considerably the economic performance of the latter prior art method.

Yet another mining method of developing an oil deposit, known in the art, involves the heating of oil-bearing bed by periodic injection of steam from underground workings located above a recovery gallery, via system of inlet wells.

Without discontinuing the injection of steam, fluid such as oil and water is periodically extracted via recovery wells drilled from the recovery gallery located in the bottom por-

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tion of the oil-bearing bed. This is followed by periodic injection of hot and then cold water, while continuing the extraction of fluid via recovery wells.

This latter prior art method, regarded by the inventors as prototype of the method according to the present invention, is accomplished in the form of either a two-horizon system or a two-stage system.

Both systems suffer from a non-uniform coverage of the oil-bearing bed by the displacement process and, as a result, from low recovery.

In the case of the two-horizon system, large amounts of heat are lost to overlying rock through the walls of inlet wells, which affects the bed-heating efficiency.

In the case of the two-stage system, the bed-heating efficiency is reduced considerably because of non-uniformity of thermal effect upon the oil-bearing bed, as a result of which the peripheral zones of the area under development are heated slowly and oil fails to assume desired fluidity, this leading to lower recovery.

It is the primary object of the present invention to develop a method of mining an oil deposit that would help increase the current oil production and the rate of oil extraction from the deposit.

It is another object of this invention to develop a method of mining an oil deposit that would help increase the efficiency of thermal effect upon the bed.

It is still another object of the present invention to develop a method of mining an oil deposit that would help re-

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duce the amount of drilling to be done in "barren", oilfree rock.

Said and other objects of the present invention are accomplished in the herein disclosed method of mining an oil deposit, which comprises:

- arranging a plurality of underground workings and recovery galleries;
- drilling recovery wells in rows from said recovery galleries;
- arranging inlet galleries, each of them in the bed between two recovery galleries near the faces of said recovery wells;
- drilling inlet wells from said inlet galleries towards said recovery wells such that said inlet and recovery wells should alternate in the oil-bearing bed portions between said inlet and recovery galleries to envelop the bed in a uniform network of wells;
- force-feeding a heat carrier to the oil-bearing bed through said inlet wells for heating the bed to a temperature at which oil assumes desired fluidity in the latter and for displacing oil to said recovery wells;
- extracting oil from the recovery wells to the recovery galleries; and
- delivering oil from the recovery galleries via underground workings to the ground surface.

The improvement of the method according to the present invention consists in that the inlet gallery is arranged near the faces of the recovery wells, while the inlet and recovery

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wells in the oil-bearing bed portion between the inlet and recovery galleries are drilled towards each other such that they should envelop the bed in a uniform network of wells.

An increase of current oil production and of the rate of oil extraction from the oil-bearing bed is attained as a result of heating the oil-bearing bed and oil contained in the latter and, consequently, as a result of reducing the oil viscosity, expanding oil and increasing reservoir pressure. Thanks to a better coverage of the bed by the process of oil displacement by the heat carrier and a more uniform heating of the bed, an increase in recovery is attained.

An increased efficiency of the bed heating process is attained as a result of reducing heat losses through the walls of inlet wells which are drilled in the oil-bearing bed, as well as owing to additional heating of the bed upon the influx of heated oil via shaft of the recovery well through less heated portions of the bed.

The efficiency of the oil production process is attained owing to an increased recovery and higher rates of developing oil deposits, as well as owing to a manifold, sometimes complete, reduction of the amount of well drilling in "barren", oil-free rock.

The herein disclosed method provides for the maximum possible degree of bed drainage by means of horizontal, flat-dipping and flat-raise wells which extend over the oil-bearing bed through dozens and hundreds of meters to interconnect its inhomogeneous zones, various channels, cracks and caverns and to increase the degree of bed completion.

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The method of the invention further provides for ensuring, along with the oil displacement mode, conditions required for a display of gravity flow of oil, as well as the maximum possible simplification of the conditions of well operation.

It is expedient that in oil-bearing beds whose top portion is made up of poorly cemented loose rock or markedly fissured rock, with high-pressure water-bearing beds located below such oil-bearing beds, the inlet and recovery galleries should be located in the bottom portion of the oil-bearing bed.

With the inlet and recovery galleries located in the bottom portion of the bed, the inlet and recovery wells are fully located in the oil-bearing bed. Naturally, this helps fully eliminate heat losses to "barren" rock through well walls due to heat conductivity. All of the heat is consumed for heating the oil-bearing bed.

It is further expedient that in oil-bearing beds made up of poorly cemented and loose rock, with beds of stable and hard rock located therebelow, the inlet and recovery galleries should be located below the oil-bearing bed.

The arrangement of the recovery galleries below the oil-bearing bed makes for improved operating conditions of raise wells thanks to a reduced possibility of sand plugging. Underground air in the inlet and recovery galleries is improved owing to the location of said galleries in oilfree rock.

Since the tops of the inlet and recovery wells are in a water-bearing bed, favorable conditions exist for their sealing. Shaft portions of wells drilled in water-bearing bed are, as a rule, an insignificant fraction of the well length.

In this case, heat losses to "barren" rock are negligible owing, first, to a reliable insulation of the wells in the top portion and, second, to the tendency of heat to move upwards, i.e., to the zone of oil extraction from the deposit.

The present invention will be better understood upon considering the following detailed description of an exemplary embodiment thereof, with due reference to the accompanying drawings in which:

Figure 1 shows the variation of the mean temperature of the oil-bearing bed over the length of a horizontal inlet well;

Figure 2 is a plan view of a portion of oil-bearing bed under development with inlet and recovery wells and underground workings (underground workings and wells are conventionally superposed in a single horizontal plane);

Figure 3 is a section taken along the line III-III of Fig. 2 for the case when the inlet and recovery galleries are located in the bottom portion of the oil-bearing bed; and

Figure 4 is a section taken along the line III-III of Fig. 2 for the case when the inlet and recovery galleries are located below the oil-bearing bed.

The herein disclosed method is realized in the following manner.

A plurality of underground workings is set up, including two shafts, namely, a winding shaft 1 (Figs. 2, 3) and a ventilating shaft 2, a mine yard 3 (Fig. 3), shaft workings which house a locomotive barn, a pumping station, storages etc. (not shown in the drawings), drifts 4, inclined workings

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5 and 6 (Figs. 2 and 3). The drifts 4 are driven above the roof of an oil-bearing bed 7 (Fig. 3) and inclined to the horizon at an angle of from 1 to 3°.

The inclined workings 5 and 6 are driven from the drifts 4 (Figs. 2 and 3) to the bottom portion of the bed or below the latter, where at least one inlet gallery 8 and recovery gallery 9 are set up.

The inlet galleries 8 are located near the faces of recovery wells (11). Both the inlet and recovery galleries (8 and 9, respectively) may be rectilinear (as shown in Fig. 2) or curvilinear, depending on the shape of the area under development.

Upon delivery of steam via horizontal or flat-raise inlet wells 10, pressure losses over the well length cause a pressure drop between the well top and face. At the same time, there is observed a temperature drop over the length of the inlet wells 10, caused by the transfer of heat to the oil-bearing bed 7 saturated with liquids.

Since low delivery pressures are employed in oil wells, low-temperature steam arrives to the tops of the inlet wells 10, while it is practically a condensate (hot water) that arrives to the well faces. Curve A in Fig. 1 indicates the mean temperature of the bed over the length of a horizontal well in one of the actual portions of the oil well.

In the bed zone adjoining the top portion of the inlet well 10 (Figs. 2 and 3), heating is carried out owing to heat conductivity inasmuch as this part of the well is cased with a string. In the zone of the oil-bearing bed 7 (Fig. 3) adjoin-

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ing the face portion of the inlet well 10, the bed is heated owing to convection heat transfer. In the face portion of said well, the pressure and temperature are rather low and have no considerable effect upon the heating of the oil-bearing bed 7.

When delivering steam at low pressures, as is often the case, the heating of the oil-bearing bed 7 is mainly accomplished owing to heat conductivity from the shafts of the horizontal inlet wells 10.

As seen from the chart (curve A) showing the well length dependence of the mean temperature (Fig. 1), the highest temperature is observed in the top portion of the well. This entails an increase of the temperature of the walls of the gallery 8 (Figs. 2 and 3) from which the wells are drilled, as well as an increased release of heat to underground air. If both inlet and recovery wells are located in one and the same gallery, this leads to aggravation of the working conditions for the personnel engaged in the recovery of oil from the recovery wells.

An increase of the amount of air used for airing causes large heat losses from the bed which, in turn, affects adversely the heating efficiency and the heat balance of the process of thermally influencing the oil-bearing bed 7 (Fig. 3).

In order to eliminate the afore-described disadvantages, the inlet and recovery galleries (8 and 9, respectively) are located in the bottom portion of the oil-bearing bed 7 or below the latter, the inlet galleries 8 being located near the faces of the bottom row of the recovery wells 11.

Oil assuming desired fluidity in the portions adjoining the tops of the inlet wells 10 arrives to the faces of the

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recovery wells 11 and then, via shafts of the recovery wells 11, to the recovery gallery 9. The heat received by oil in said zone is partly transferred to the bed upon oil movement towards the recovery gallery 9. This makes for the heating of the oil-bearing bed 7 over the entire volume thereof thanks to a better coverage of the bed by the heat carrier which, in turn, helps increase the efficiency of heating the oil-bearing bed 7 and recovery factor thereof.

At the same time, temperature conditions permissible from the standpoint of labor protection and safety regulations are maintained in the recovery gallery 9 where most of the personnel members are stationed.

The heating front having a preset temperature is gradually moving towards the recovery gallery 9 (in the direction of oil extraction via recovery wells) since the heat carrier is delivered via inlet wells 10 whose tops are near the faces of the recovery wells 11. Therefore, the extraction of oil and movement of the heating front are effected in the same direction. The time of the heating front arrival to the recovery gallery 9 can be controlled by the delivery pressure and heat carrier temperature, which, in turn, along with the better coverage of the bed by the heat carrier, offers an important technological advantage such as the setting up of proper working conditions for the personnel in said recovery gallery 9 owing to normalization of the temperature conditions of air in said gallery.

The inlet wells 10 and recovery wells 11 in the oil-bearing bed portion between the inlet gallery 8 and recovery

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gallery 9 are drilled towards each other such that they should envelop the bed in a uniform network of wells.

The inlet wells 10 are drilled from the inlet gallery 8 uniformly over the area under development. In particular, the inlet wells 10 may be drilled parallel to each other, as shown in Fig. 2.

The recovery wells 11 are drilled from the recovery gallery 9 (Figs. 2, 3) also uniformly over the area under development such that the tops of the inlet wells be located near the faces of the recovery wells. In the case of a rectilinear recovery gallery 9, the recovery wells 11 are drilled parallel to each other.

The heat carrier (for example, steam) is delivered to the tops of the inlet wells 10 from a boiler unit 12 located on the ground surface, via ground pipeline 13 through a steam-supply well 14 and underground pipelines (not shown) located in the drifts 4.

The heat carrier is injected into the oil-bearing bed 7 via system of inlet wells 10. Inasmuch as the tops of the inlet wells 10 are located near the faces of the recovery wells 11, oil first assumes desired fluidity in the portions of the oilbearing bed 7 adjoining the zone of the tops of the inlet wells 10.

Oil is fed via the shaft of the recovery well 11 to the recovery gallery 9 and then to ditches or pipelines provided in the drifts 4.

Together with water supplied to the ditches or pipelines, oil is conveyed by gravity owing to the inclination of

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the workings to the horizon on the order of $1-3^{\circ}$ towards oil trapping units (not shown in the drawings) where it is separated from the bulk of water. Pumps can be used for conveying oil with associated water to said units via pipelines. From the oil trapping units oil is pumped over to central underground oil collectors (not shown in the drawings) from which it is fed, following primary preparation and preheat, via pipelines and through special wells 15 or through the shaft into oil storage tanks 16 located on the ground surface.

The method will remain essentially the same if the drifts 4 (Fig. 4) are provided below the oil-bearing bed 7. Moreover, such an arrangement of the drifts offers better conditions for the delivery of oil thereto from the recovery galleries 9.

In this case, the conveyance of oil can be effected by gravity from the top of the recovery wells 11 to the oil trapping units.

The inlet and recovery galleries (8 and 9, respectively) may have the form of two twin workings (as shown in Fig. 2), as well as of a single working.

In any case, the extent of some or other galleries depends, among other things, upon the possibility of their reliable airing in the course of driving and operation.

The oil well ventilation system should meet the requirements of labor protection and safety regulations for the service personnel.

In another embodiment of the disclosed method, when the top portion of the oil-bearing bed 7 is made up of poorly

cemented, loose or markedly fissured rock, with a high-pressure water-bearing bed located below the oil-bearing bed, the inlet and recovery galleries are located in the bottom portion of the oil-bearing bed.

In this embodiment, following the setting up of the plurality of underground workings (shafts, mine yard, shaft workings, drifts in the overlying horizon, inclined workings), the method of the invention is accomplished by executing the following steps.

1) Rectilinear recovery galleries 9 are provided in the bottom portion of the oil-bearing bed 7 at a distance of 500-700 m from each other (Figs. 2, 3);

2) in the design zone of the faces of the bottom row of the inlet wells 11 there are arranged rectilinear inlet galleries 8 located between the recovery galleries 9 in the bottom portion of the bed (in the top portion of the zone of transition from oil to bottom water);

3) recovery and inlet wells (10 and 11, respectively) are drilled at a distance of 10-20 m between each other in the portion of the oil-bearing between the inlet and recovery galleries (8 and 9, respectively). The wells are arranged in several rows (layers) over the bed thickness. In each row (layer), the inlet and recovery wells (10 and 11, respectively) are arranged alternately with each other or, depending upon geological conditions, several (2 to 5) recovery wells 11 are located between two inlet wells 10.

4) the heat carrier (such as steam) is injected into the oil-bearing bed 7 via inlet wells 10 at a pressure of from 3 to 10 kgf/cm², with time intervals of from 15 to 30 days and pauses of the same duration.

Then, all of the inlet wells 10 of the element (area) under development are divided into groups, with the delivery of steam into each one of them being effected alternately, with the afore-mentioned time intervals of steam injection and shutdown of inlet wells 10;

5) intermittent extraction of fluid (oil and water) is effected from the recovery wells 11;

6) the cycles of heat carrier injection into the bed and oil extraction are repeated until full economically practical recovery of oil from the area under development.

It still another embodiment of the method of the invention in the case of oil-bearing beds 7 made up of poorly cemented and loose rock, with beds of stable and hard rock located therebelow, inlet and recovery wells (8 and 9, respectively) (Fig. 4) are located below the oil-bearing bed.

In this latter case, the method of the invention can be accomplished mainly through the execution of the aforescribed steps, with due regard for the above-mentioned arrangement of the inlet and recovery galleries (8 and 9, respectively).

The operating conditions of the recovery wells 11 according to said latter embodiment are improved over those described above owing to a reduced possibility of sand plugging. Underground air in the workings is likewise improved owing to the location of the latter in oil-free rock.

The use of the herein disclosed method of mining an oil deposit results in an increased current production of oil and rate of oil extraction from the oil-bearing bed 7. Conditions are provided for a more uniform and intensive heating of the

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oil-bearing bed, as well as for a fuller coverage of the bed by the process of oil displacement by the heat carrier, which makes for an increased recovery and, as a result, for higher efficiency of the production of highly viscous oil.

The present invention can be used no less advantageously in the production of fluid asphalts.

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The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:-

1. A method of mining an oil deposit, wherein a plurality of underground workings and recovery galleries are arranged in the oil deposit;
recovery wells are drilled in rows from said recovery galleries;
inlet galleries are arranged, each located in a bed between two of said recovery galleries near the faces of said recovery wells; inlet wells are drilled from said inlet galleries towards said recovery wells such that said inlet and recovery wells alternate in oil-bearing bed portions between said inlet and recovery galleries to envelop the oil-bearing bed in a uniform network of wells;
a heat carrier is delivered to the oil-bearing bed through said inlet wells for heating the bed to a temperature at which oil assumes desired fluidity in said bed and for displacing oil to said recovery wells;
oil is extracted from said recovery wells to said recovery galleries;
oil is conveyed from said recovery galleries via said workings to the ground surface.

2. A method as set forth in claim 1, wherein said inlet and recovery galleries are located in the bottom portion of the oil-bearing bed.

3. A method as set forth in claim 1, wherein said inlet and recovery galleries are located below the oil-bearing bed.



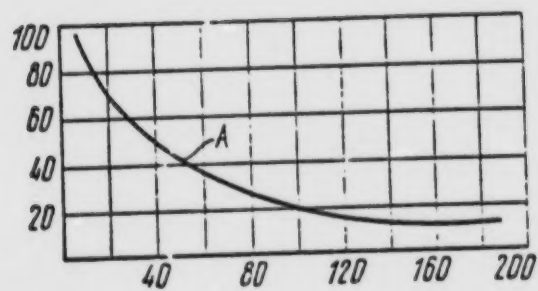


FIG. 1

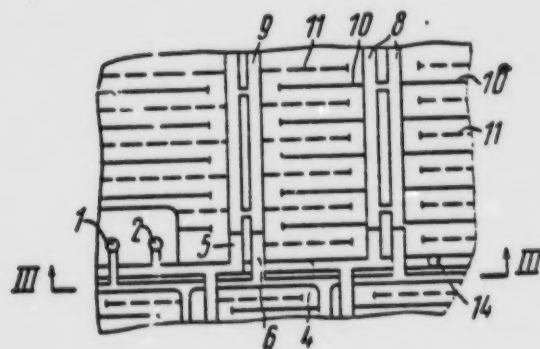


FIG. 2

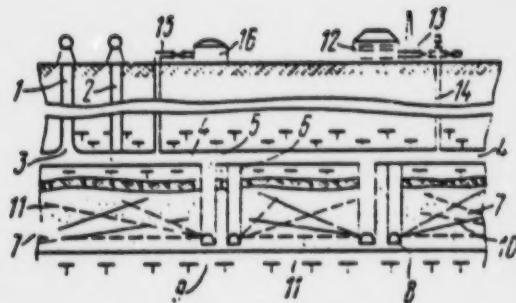


FIG. 3

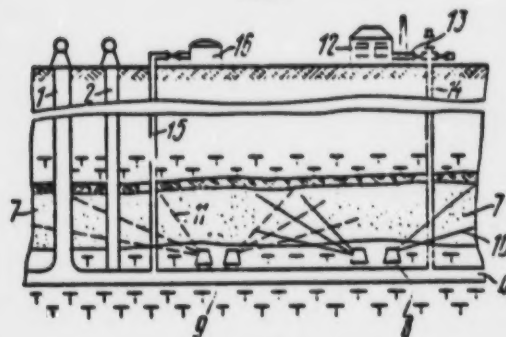


FIG. 4

[US Patent 4,390,067]

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 INVENTED BY REGISTERED PATENT OFFICE
ALBERTA OIL SANDS ALBERTA OIL SANDS

Alberta OIL SANDS

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(54) METHOD OF TREATING RESERVOIRS CONTAINING VERY VISCOUS
CRUDE OIL OR BITUMEN

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METHOD OF TREATING RESERVOIRS CONTAINING
VERY VISCOUS CRUDE OIL OR BITUMEN

BACKGROUND OF THE INVENTION

This invention relates to a novel method of treating subsurface deposits containing heavy or viscous oil so that it may be recovered using hot fluid displacement techniques.

There exist throughout the world major deposits of heavy oils which, until recently, had been substantially ignored as sources of petroleum since the oils contained therein were not recoverable using ordinary production techniques. For instance, only lately has much interest been shown in the heavy oil deposits of Alberta province in Canada even though the deposits are both close to the surface and represent an estimated petroleum resource upwards of many billion barrels. The expense involved in the production of these oils stems from the fact that they are quite viscous at reservoir temperatures. A viscosity of 10,000 centipoise to several million centipoise characterizes Athabasca crude oil. Unless the deposit is on the surface and the heavy-oil-containing material can be mined and placed in a retort for separation from its matrix, some method of treating the deposit in-situ need be utilized for the realization of any substantial petroleum recovery.

Intervell displacement has been recognized as the most efficient method of in-situ recovery of heavy oils. However, before displacement can commence, a warm and liquid communicating path must be established between wells since viscous oil will not flow at any commercial rate until its viscosity is reduced by heat. In-situ or reservoir heating to try to create this communicating path is generally done by steam stimulation, i.e., injection of steam at above fracturing pressure and subsequent production, on an individual well basis. This process does not result in a well defined heated volume. Since the steam is injected into the formation above fracture pressure, the steam takes the unpredictable path of least resistance in the often unconsolidated strata containing the viscous oils.

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1 Consequently, oil which would be recoverable by the present invention is
2 not produced. For these reasons it is a formidable task to recover a
3 substantial percentage of the heavy oil in a selected formation while
4 efficiently utilizing available steam. This invention is intended to
5 provide an effective manner for treating and recovering viscous oils.

6 A number of methods have been suggested for in-situ thermal
7 recovery of viscous oil deposits.

8 One of the earliest methods entails the steps of first, drilling
9 a single vertical borehole into the petroleum-bearing formation and then
10 injecting a heated fluid such as steam or water into the formation thereby
11 causing the hydrocarbon to become less viscous and flow. The thusly-heated
12 hydrocarbon is finally pumped from the same vertical borehole. Obviously
13 this method is slow, since there is no mean hydraulic force to continually
14 urge the oil towards the wellbore and no source of heat to maintain it in a
15 liquid, or at least pumpable, state. For these reasons, the proportion of
16 petroleum that can be recovered from a particular formation is quite low.

17 Another early suggestion, in U.S. Pat. No. 3,349,845, to Holbert
18 et al, provides a somewhat complicated method for recovering viscous oils
19 from shale formations. The process entails first drilling a vertical
20 injection well and thereafter forming a system of vertical fractures which,
21 if desired, may be propped open with sand or other granular solids. A
22 horizontal, or output well, is then drilled to intersect the vertical
23 fracture system. A heated petroleum corridor is established by heating
24 the injection well under a low gas pressure. The heating is continued
25 until a zone at least 40 or 50 feet along the wall of the vertical injection
26 well is created. Holbert et al suggests that the entire stratum between
27 injection and output well can be heated but that is usually neither necessary
28 nor desirable. The fractures are then plugged at the injection well.
29 Plugging provides assurance that the subsequently added displacement

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1 fluid, which may be steam, displaces the oil into the output well rather
2 than merely flowing through the fractures.

3 Holbert et al., although alleging the utility of its disclosed
4 process with respect to tar sands, is apparently quite specific to oil
5 shales and of only minor relevance to tar sands. For instance, vertical
6 fracturing is a required step in the process, and yet U.S. Patent No.
7 4,020,901, to Pisio et al., indicates that attempts to fracture tar sand
8 formations in a controllable manner do not meet with success. Vertical
9 fractures often terminate uselessly at the surface. The fractures often
10 tend to "heal" as mobilized viscous petroleum flows through the cracks and
11 cools to its immobile state. Pisio et al., additionally mentions that tar
12 sands frequently underlie intermediate overburden layers which are easily
13 fractured.

14 The Holbert et al. process is not particularly useful at a viscous
15 oil deposit such as that found at Athabasca. The Athabasca tar sands are
16 at a nominal depth of about 250 feet. Such depth is too deep to mine and
17 much too shallow to create suitable fractures.

18 Holbert et al. additionally suggests propping open the fractures
19 with some known proppant such as sand. When the stratum under considera-
20 tion is oil shale, propping is a step which facilitates oil flow. However,
21 in the case of a tar sand which is composed of a viscous oil and sand, the
22 use of sand as a proppant is somewhat akin to "carrying coals to Newcastle."
23 The proppant supply becomes part of the sand matrix and the fracture closes.

24 Finally, it is generally accepted that fracturing an unconsoli-
25 dated formation such as by tar sand gives unpredictable results, at least
26 with regard to the orientation of the fracture. On the other hand, consoli-
27 dated formations, such as the oil shales of Holbert et al., can be fractured
28 with reasonably predictable results. The disclosure in Holbert et al.
29 requires knowledge of the fracture's orientation so that the horizontal

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1 output well can be drilled to intersect the fractures. Knowledge of fracture
2 orientation in unconsolidated tar sands is not, as a rule, available.

3 A subsequent development is found in U.S. Patent No. 3,386,508,
4 to Bielstein et al. This process for recovering viscous crude oils involves
5 sinking a large central well, having a bore diameter of 1 to 10 feet, into
6 a subsurface formation containing oil. A number of injection wells are
7 then slant-drilled to intersect the central well within the subsurface oil-
8 bearing stratum. Steam is then introduced into the injection wells only at
9 the upper end of the stratum. Displaced heated oil permeates the walls at
10 the lower end of the injection wells and passes into the central well where
11 it accumulates and is pumped to the surface.

12 Bielstein et al. does not heat an open horizontal borehole and
13 then plug it as is done in the process of the present invention.

14 An additional set of related developments is found in U.S. Pat.
15 Nos. 3,994,340; 4,020,901; and 4,037,658, to Anderson et al., Pisio et al.,
16 and Anderson respectively. Each produces a heated horizontal corridor by
17 the physical placement of long heat exchangers in the tar sand stratum.
18 The three differ from each other principally in the design of their heat
19 exchangers. Each of these specifications additionally discusses the produc-
20 tion problems which are unique to tar sands including the difficulty,
21 mentioned above, of creating and maintaining an effective fracture network.
22 None of the three suggests the straightforward and simple method of treating
23 the petroleum-bearing stratum disclosed herein.

24 Other methods of attaining corridors of heated viscous petroleum,
25 from which the heated oil can be displaced, are known. For instance, U.S.
26 Patent Nos. 4,010,799 and 4,084,637, to Kern et al. and Todd respectively,
27 teach a process in which a number of vertical wells are drilled down into
28 the oil-bearing stratum, electrodes are inserted into the wells, and a
29 voltage imposed across the electrodes in adjacent wells. Although it is
30 understood that a prototype well involving such a process has been drilled,

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1 it is apparent that complete control of a resulting heated chamber position
2 is not readily possible. The electric current will take the path of least
3 resistance irrespective of where the driller would place the chamber.
4 This problem is especially pronounced in areas where oil-bearing formations
5 lie in close vertical proximity to electrically-conductive aquifers.

6 SUMMARY OF THE INVENTION

7 This invention relates to a method of treating subsurface forma-
8 tions containing viscous oil, heavy oil, or bitumen so that these oils may
9 be recovered in a reliable manner during a subsequent production operation.
10 This invention, in its simplest form, calls for preparing the oil deposit
11 by drilling a relatively horizontal borehole for a distance within the oil-
12 bearing stratum, heating the length of the borehole with an appropriate
13 fluid, filling the borehole with a substantively nonporous material, and
14 thereby producing a zone or corridor containing heated oil which is subse-
15 quently recoverable by known displacement techniques.

16 Since the heated corridors produced by the inventive treatment
17 process are so well-ordered, recovery techniques using a grid like pattern
18 of injection and production wells are possible. Effective use of such a
19 pattern results in a high percentage of petroleum recovery.

20 The inventive process has the advantage of being usable in both
21 thin and thick oil-bearing strata as well as in those which are adjacent to
22 water-bearing layers.

23 BRIEF DESCRIPTION OF THE DRAWINGS

24 FIGURES 1A and 1B show a seven-well configuration or seven spot
25 repeated pattern, in cutaway perspective and vertical section respectively,
26 useful for practicing the present invention.

1 FIGURES 2A - 2C show the progression of the shape of an H-shaped
2 heated zone or corridor configuration as oil is displaced.

3 FIGURES 3A and 3B show a five spot repeated pattern in cutaway
4 perspective and vertical section, respectively, useful for practicing the
5 present invention.

6 FIGURE 4A shows a front semi-elevation of a field having a
7 number of seven spot repeated patterns.

8 FIGURE 4B shows an elevation of the field of FIGURE 4A.

9 FIGURES 5A and 5B show, respectively, a semi-elevation and an
10 elevation of a field using interconnected 3-spot patterns.

11 DESCRIPTION OF THE PREFERRED EMBODIMENTS

12 A central feature of the inventive process rests in the attain-
13 ment of a heated oil corridor within the oil-bearing stratum by the steps
14 of drilling a horizontal borehole which extends for a distance within the
15 subject stratum, heating the borehole and oil in its environs, and effec-
16 tively plugging the heated horizontal borehole. A displacement fluid, such
17 as steam, may subsequently be injected at one end of the heated corridor
18 and displaced oil produced at the other. Plugging the horizontal borehole
19 provides assurance that the displacement fluid performs its desired function
20 rather than running uselessly through an open horizontal borehole.

21 This invention is not limited to a single horizontal heated
22 chamber having an injection well at one end and a producing well at the
23 other. It is normally desirable to lay out a particular field so that
24 various horizontal heated corridors intersect in a chosen manner within the
25 oil-bearing stratum. In this way the associated injection and production
26 wells can serve multiple duty. A single displacement fluid injection well
27 is then able to inject fluid directly or indirectly into a number of heated
28 corridors and a single production well similarly may service a number of
29 corridors. A number of well patterns suitable for optimum utilization of
30 the invention are disclosed below.

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1 For the purposes of this disclosure, a repeating layout of injection and production wells as connected by horizontal heated corridors is
2 known as a "pattern". The surface wells in such a "pattern" are known as
3 "spots". Hence a "five spot pattern" is a layout of five surface wells
4 interconnected in some manner by heated corridors in the oil-bearing stratum.
5 An "array" will be a collection of "patterns" possibly interconnected and
6 possibly not.

7 Several alternative well patterns are contemplated as suitable
8 for attainment of the desired heated corridors and having a configuration
9 of injection and production wells satisfactory for subsequent production.
10 In dealing with a petroleum-bearing stratum extending over a large area, it
11 may be necessary to make a determination, based on the economics of the
12 field, whether to produce the field with a large number of wells arranged
13 in an array of well patterns, each having injector and producer wells, or
14 simply with a single large pattern. The well configurations disclosed
15 herein are suitable for both single patterns and multiple pattern fields.
16 The consideration of well spacings, i.e., whether to use a single large
17 pattern or multiple small ones, is a normal one in developing any oil field
18 whether using this invention or other more conventional techniques.

19 One particularly useful well pattern is schematically depicted,
20 in cutaway shadow perspective, in FIGURE 1A and in vertical cross-section,
21 as viewed from the injection well end of the pattern, in FIGURE 1B. The use
22 in a particular field of well patterns, such as the one in FIGURES 1A and
23 1B, in an interconnected array is discussed in some detail in conjunction
24 with FIGURE 4.

25 The seven spot pattern shown in FIGURE 1A is produced by drilling
26 four approximately vertical wells 101, 102, 104, and 105 down from the
27 surface 109 substantially into the oil-bearing stratum 108. The spacing of
28 these wells, as mentioned above, is determined by the economics of recovery
29 in the particular field. The economic considerations would include such
30

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1 diverse information as the thermal conductivity of the oil stratum, viscosity
2 of the heated oil, thickness of the oil stratum, and the type of horizontal
3 drilling equipment available. In any event, horizontal distances between
4 wells can be up to 1,000 feet or more in an oil stratum of about 150 feet.
5 Horizontal wells 103 and 106 are then drilled to intercept, respectively,
6 vertical wells 101, 102 and 104, 105 within the oil strata. A third
7 horizontal well 107 is drilled which intersects the horizontal legs of
8 wells 103 and 106 approximately halfway between their respective vertical
9 wells. Methods for drilling horizontal wells are well known in this art
10 and one suitable method is discussed at some length in Holbert et al.
11 supra. Although the vertical placement of the horizontal wellbores within
12 the stratum is not particularly critical, it is highly desirable to place
13 them in the approximate vertical center of the stratum. The oil in many
14 Canadian fields has a formation temperature of 45°-55°F. By placing the
15 horizontal boreholes in the center, less of the applied heat entering via
16 the heating stream is lost to the surrounding non-productive strata.
17 Consequently, the heated channel will be larger in diameter.

18 The term "intercept", in referring to boreholes in this specifi-
19 cation, is intended to include not only those boreholes which actually
20 interconnect, but also those which are or will be effectively connected by
21 a heated channel. For instance, vertical well 101 "intercepts" horizontal
22 well 103 if it passes through the region about horizontal borehole 103 that
23 eventually becomes a heated channel.

24 The order in which the wells are drilled is not important. It is
25 contemplated that in some instances the vertical wells may be drilled
26 during the time the horizontal wells are undergoing heat treatment or even
27 thereafter.

28 In any event, before heating the horizontal legs of wells 103,
29 106 and 107 to establish the heated corridors, the wells should be cased
30 and perforated. A steam injector of tubing may be inserted to near the end

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1 of these wells. Steam may then be introduced into the well through the
2 tubing and condensate removed up through the annulus. Less desirably,
3 since more heat will be lost to unproductive upper strata, the steam may be
4 injected in the annulus and condensate returned up the tubing.

5 Vertical wells 101, 102, 104, and 105 are cased and also perforated
6 within the oil-bearing stratum. It may be necessary to heat the perforated
7 portion of a vertical well to provide assurance that either the vertical
8 well or the heated region around the vertical well intersects the heated
9 corridor around the horizontal leg. For instance, it may be necessary to
10 heat the portion of wells 101 or 102 within the oil-bearing layer illustrated
11 in FIGURE 1B. Drilling is an inexact science and consequently well 103 may
12 miss wells 101 or 102. Heating wells 101 or 102 to create a continuous hot
13 oil corridor therebetween allows wells 101 and 102 to be used as injector
14 wells.

15 The heating step should be continued until an amount of heat
16 approximately equal to that found in 30-100 barrels of steam per linear
17 feet of horizontal wellbore has been introduced into the formation. The
18 steam may be wet and desirably would have a high temperature and a pressure
19 as high as is possible without reaching the fracturing pressure of the
20 formation. A pulse test should be performed after the heating step is
21 completed to assure the existence of a heated liquid corridor between wells
22 101 and 102 as well as between wells 104 and 105. Of course, if the pulse
23 test fails to confirm the existence of liquid corridors between the pertinent
24 wells, heating should be started again.

25 The horizontal borehole is then plugged along its entire length
26 by filling with an effectively nonporous material such as cement or a
27 mixture of clay and rock as, for instance, shown at 121 in FIG. 1B.
28 FIG. 1B depicts the pattern shown in FIG. 1A after the step of heating has
29 been completed and the horizontal portion of well 103 has been plugged with
30 cement 121.

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1 The extent of the now-mobile hot oil corridor is shown at 123 as
2 is the end of the heated corridor 122 associated with intersecting horizontal
3 well 107. Steam or other suitable displacement fluid is heated in a boiler
4 110 and injected through steam lines 120 and introduced to the heated
5 corridor 123 behind thermal parking means 124 in both wells 101 and 102.
6 Although the use of steam lines 120 and packer 124 is preferable in that
7 the annular spaces surrounding steam lines 120 are fairly effective insulators,
8 injection of a heated displacement fluid directly into the cased vertical
9 wells is acceptable. The heat and hydraulic pressure supplied by the steam
10 tends to displace the heated oil from the ends of chamber 123 down into
11 heated chamber 122 (as shown by the arrows in FIGURE 1A) and from there
12 into the two recovery wells, 104 and 105, at the opposite end of heated
13 chamber 122. Although steam is discussed as the displacement fluid through-
14 out this specification, it should be understood that other displacement
15 fluids including hydrocarbon and other solvents, micellar dispersions, and
16 surfactants may be added as desired.

17 Wells 104 and 105 can, in the alternative, be used as injection
18 wells and wells 101 and 102 used as producers.

19 FIGURES 2A-2C are overhead views of the heated corridors, 122 and
20 123, surrounding wells 101, 102, 104, and 105 as those corridors grow
21 during the production step illustrated in FIGURES 1A and 1B. The H-shaped
22 configuration of the corridors is particularly advantageous to use with the
23 heating step disclosed herein because of the potential for exceptionally
24 high recovery efficiency. As steam displacement of the viscous oil takes
25 place, the hot liquid corridors, e.g., 122 and 123 in FIGURE 2A, tend to
26 increase in diameter, and the once-right-angle meeting between corridor 122
27 and the other corridors begins to smooth in the manner shown in FIGURE 2B.
28 Further displacement continues such trend, as shown in FIGURE 2C.

29 A similar and more desirable well layout producing the H-shaped
30 heated corridors is depicted in FIGURES 3A and 3B. This embodiment, which

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1 is especially suitable for a field requiring a single five-spot pattern,
2 uses only two vertical wells, 201 and 204. Horizontal wells 202 and 203,
3 similarly to wells 103 and 106 in FIGURE 1A, come down from the surface and
4 take a largely horizontal route through the oil-bearing stratum to intersect
5 wells 201 and 204. Horizontal well 205 intersects both wells 202 and 203
6 at a predetermined site within the stratum. This embodiment is more desirable
7 than that found in FIGURES 1A and 1B since fewer wells are drilled.

8 Casing, perforating, and heating the horizontal wellbore is
9 undertaken in a manner similar to that discussed above with regard to the
10 configuration of FIGURES 1A and 1B.

11 The major significant difference between these embodiments lies
12 in the plugging of the horizontal portions of wells 202 and 203. Only the
13 lower portion of the horizontal bore is filled, with cement or clay and
14 rock, 215 in FIGURE 3B, since the subsequent displacement step requires the
15 displacement fluid to come in contact with the heated chamber 213. As in
16 the previously discussed embodiment, the displacement steam is generated in
17 a steam generator 210 and flows through steam line 211 into wells 201 and
18 202 where it is injected into heated chamber 213 through perforations in
19 the well casings. Packers 212, maintain the steam in contact with the
20 heated bed 213. The steam tends to displace the viscous oil therein towards
21 heated corridor 214 which surrounds plugged horizontal wellbore 205, through
22 corridor 214, and from there into production wells 202 and 203.

23 Other configurations of injector and producer wells would be
24 apparent to one having skill in the art based on this disclosure and would
25 include such variations as: a single injection well and a single production
26 well coupled by a heated corridor produced by the inventive heating method;
27 a T-shaped configuration having either two injection wells on the cross-bar
28 and one production well on the base of the 'T' or alternatively two produc-
29 tion wells on the ends of the cross-bar and one injection well on the base
30 of the 'T', all connected by heated corridors produced by the method of the

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1 invention; or a square with wells at each corner and one in the center in
2 which the corners are used either as producer or injection wells and the
3 center, respectively, is used as an injection or producer well.

4 Similarly, as mentioned above, it may be desirable to repeat a
5 pattern of injector and production wells so as to effectively deplete a
6 particular field. FIGURE 4A provides a semi-elevation of such arrangement
7 using an array of the seven spot pattern depicted in FIGURES 1A and 1B.
8 FIGURE 4B provides an aerial elevation of the arrangement of FIGURE 4A.
9 Producer wells 104 and 105 are in Row B of FIG. 4B and injection wells 101
10 and 102 are in Row C. Each well in Rows A and C is an injector well and is
11 in hot corridor communication (as schematicized in the straight lines in
12 the drawing) with the injector wells adjacent to it. Each injector well is
13 in hot corridor communication through the M-network to the producer wells
14 of Rows B and D.

15 Such an arrangement provides a multitude of sources for heat and
16 hydraulic pressure on the heated oil as it moves towards a production well.
17 For instance, well 105 produces oil displaced by steam from both injector
18 wells 102 and 120 via the paths shown on FIGURE 4B.

19 FIGURES 5A and 5B illustrate what could be considered a three-
20 spot pattern which must be used in an interlocking array. The pattern, as
21 shown in FIGURE 5A, consists of two relatively parallel horizontal boreholes,
22 301 and 303, which are interconnected within the oil-bearing stratum by a
23 crossing third horizontal borehole 305 to form a grid-like array. The
24 casing, perforating, heating and plugging steps are executed on these
25 horizontal boreholes in a manner similar to the steps discussed above with
26 respect to the five-spot and seven-spot patterns.

27 Other horizontal wells are provided which meet so as to form a
28 grid-like network of reasonably continuous horizontal boreholes within the
29 stratum. Thus, the horizontal portion of well 301 meets the horizontal
30 portion of wells 307 and 309 to form a single continuous heated corridor.

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1 Some point in the borehole near its entry point into the reservoir is near
2 the termination point of another horizontal well. A similar relationship
3 exists between well 303 and its adjacent brothers and also well 305 and its
4 adjacent wells.

5 The displacement flow, as shown in FIGURE 5B, is more circuitous
6 than in the array illustrated in FIGURES 4A and 4B, but the overall expense
7 is less because of the lower number of wells drilled.

8 As in FIGURE 4E, the wells in rows A and C are used as injection
9 wells and those in rows B and D are producers.

10 The foregoing disclosure and description of the invention are
11 only illustrative and explanatory thereof. Various changes in size, shape
12 and details of the illustrated construction may be made within the scope of
13 the appended claims without departing from the spirit of the invention.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method for treating a field having a reservoir containing viscous oil or bitumen comprising the steps of:

providing at least two boreholes extending downward from the surface at least into the reservoir,

providing at least one generally horizontal borehole within the reservoir connecting at least two boreholes extending from the surface,

introducing a heated fluid into said horizontal borehole in an amount sufficient to at least soften said viscous oil or bitumen for a distance substantially along said at least one generally horizontal borehole within the reservoir,

substantially plugging said at least one horizontal borehole within the reservoir,

introducing a heated displacement fluid into at least one borehole extending downward from the surface within the reservoir at the juncture between the plugged borehole said downwardly extending borehole, and

withdrawing said viscous oil or bitumen from a borehole extending downward from the surface at a point remote from the displacement fluid introduction point.

2. The method of claim 1 wherein said at least two boreholes extending downward from the surface are substantially vertical.

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3. The method of claim 1 wherein at least one of the boreholes extending downward from the surface and at least one of said horizontal boreholes within the reservoir are the same borehole.
4. The method of claim 1 wherein the heated fluid is steam.
5. The method of claim 4 wherein steam pressure in said at least one horizontal borehole approaches or is less than the localized fracturing pressure of the reservoir.
6. The method of claim 4 or 5 wherein steam flow is terminated after 50-100 barrels of steam per linear foot of horizontal borehole in the reservoir have been added.
7. The method of claim 1 wherein the reservoir is vertically adjacent a water-containing layer.
8. The method of claim 1 wherein said at least one horizontal borehole is plugged with either cement or a mixture of clay and rock.
9. The method of claim 1 wherein the heated displacement fluid is steam.
10. A method for producing viscous oil or bitumen from a reservoir containing same comprising the steps of:
providing first, second, third and fourth boreholes extending down from the surface at least into the reservoir, spaced apart in a generally

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rectangular configuration so that the first borehole is on the corner adjacent the second and the fourth on the rectangle,

providing two horizontal boreholes within the reservoir connecting first and second boreholes and third and fourth boreholes,

providing a horizontal borehole connecting the horizontal boreholes between first and second boreholes and third and fourth boreholes approximately at the midpoints between first and second boreholes and third and fourth boreholes,

introducing a heated fluid into each of the horizontal boreholes in an amount sufficient to at least soften said viscous oil or bitumen,

substantially plugging each of said horizontal boreholes within the reservoir,

introducing a heated displacement fluid into first and second boreholes at their junction with the plugged horizontal boreholes,

withdrawing said viscous oil or bitumen from third or fourth boreholes.

11. The method of claim 10 wherein at least one of the heated fluid and the heated displacement fluid is steam.

12. The method of claim 10 wherein the reservoir is vertically adjacent a water-bearing layer.

13. The method of claim 10 wherein the horizontal wellbores are plugged with a material selected from cement and a mixture of clay and rock.

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14. A method for treating a field having a reservoir containing viscous oil or bitumen comprising the steps of:

providing a number of generally horizontal boreholes within a reservoir each having an entry point into the reservoir and a termination point within the reservoir, and arranged in a grid-like array with the termination point of a majority of said boreholes each being in near proximity to the entry point of another horizontal borehole,

introducing a heated fluid into each of said horizontal boreholes in an amount sufficient to at least soften said viscous oil or bitumen,

substantially plugging each of said horizontal boreholes within the reservoir.

15. The method of claim 14 wherein the heated fluid is steam.

16. The method of claim 15 wherein steam pressure in said horizontal boreholes approaches or is less than the localized fracturing pressure of the reservoir.

17. The method of claim 15 or 16 wherein steam flow is terminated after 50-100 barrels of steam per linear foot of horizontal borehole in the reservoir have been added.

18. The method of claim 14 wherein the reservoir is vertically adjacent a water-containing layer.

19. The method of claim 14 further comprising the steps of:

introducing a heated displacement fluid into the reservoir at one end of each of said plugged horizontal boreholes,

withdrawing said viscous oil or bitumen at a point on said plugged horizontal boreholes remote from the displacement fluid introduction site.

20. The method of claim 19 wherein the heated displacement fluid is steam.

21. The method of claim 14 wherein each of said horizontal boreholes is plugged with either cement or a mixture of rock and clay.

22. The method of claim 13 further comprising the steps of:

introducing a heated displacement fluid into the reservoir at one end of each of said plugged horizontal boreholes,

withdrawing said viscous oil or bitumen at a point on said plugged horizontal boreholes remote from the displacement fluid introduction site.

23. The method of claim 22 wherein the heated displacement fluid is steam.

24. The method of claim 18 further comprising the steps of:

introducing a heated displacement fluid into the reservoir at one end of each of said plugged horizontal boreholes,

withdrawing said viscous oil or bitumen at a point on said plugged horizontal boreholes remote from the displacement fluid introduction site.

25. The method of claim 24 wherein the heated displacement fluid is steam.

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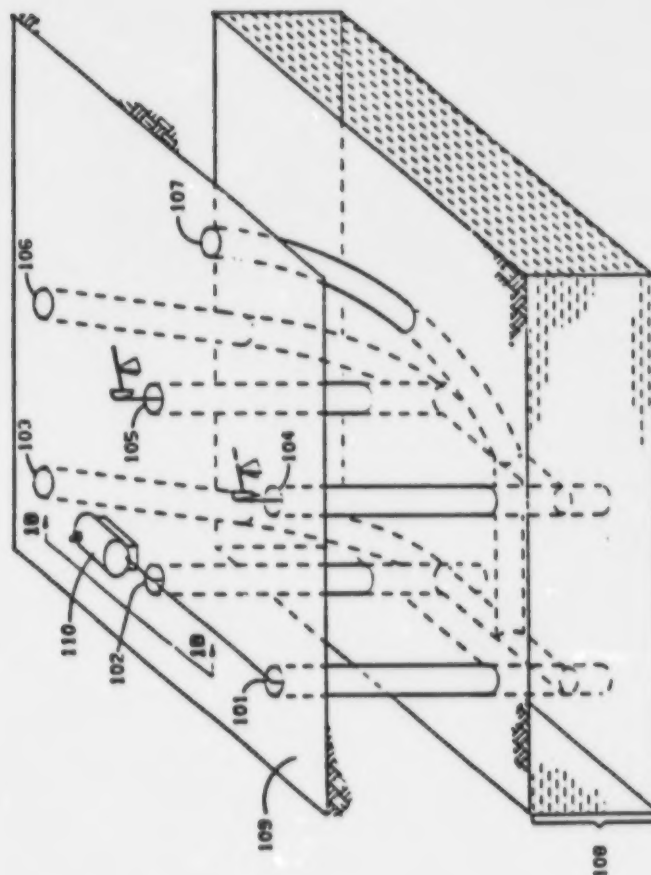
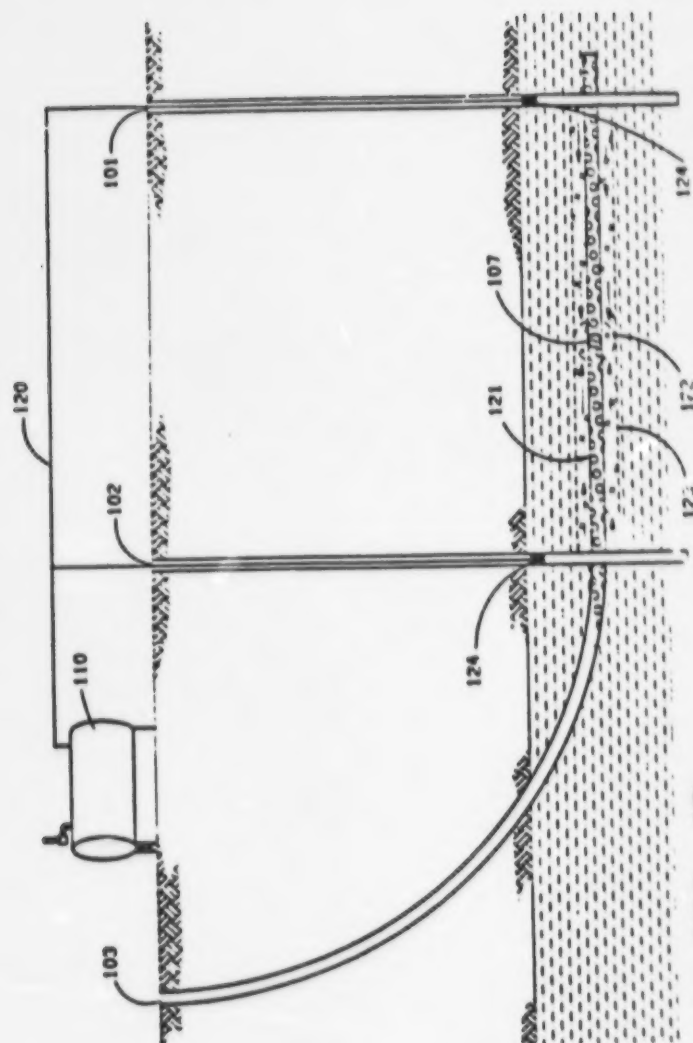


FIG. 1A

Full of Light



சுவாமிநாதர்

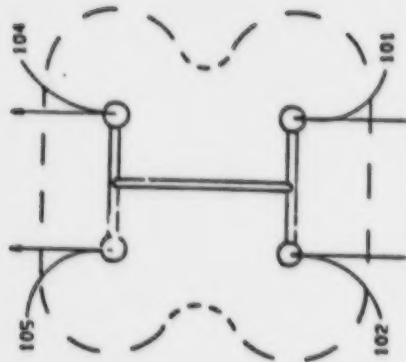


FIG. 2C

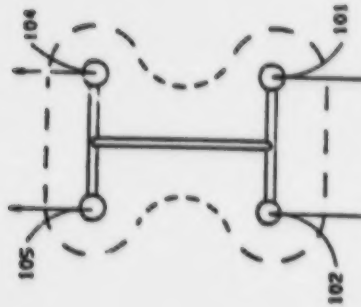


FIG. 2B

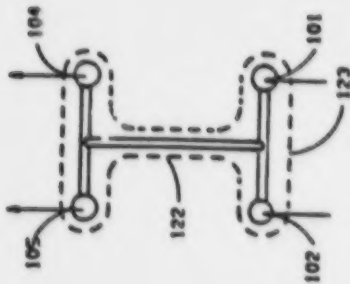


FIG. 2A

John H. Hyman

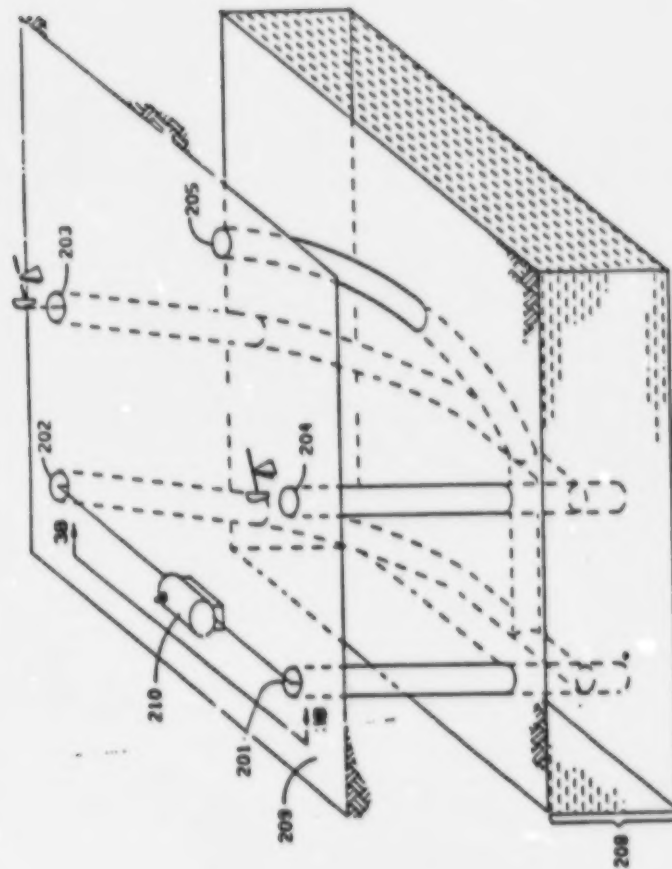
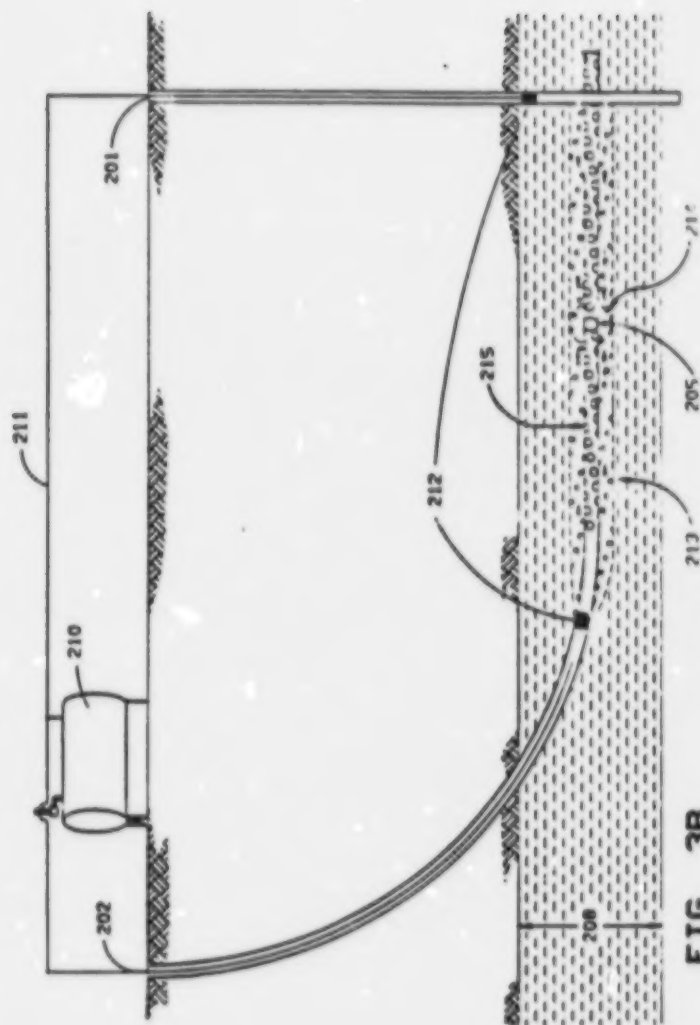


FIG. 3A

See Fig. 3B



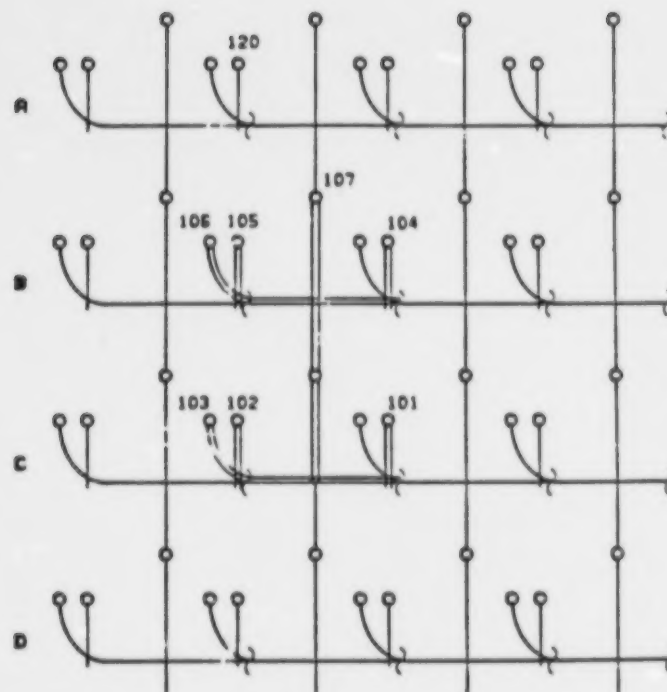


FIG. 4A

James G. Lyle

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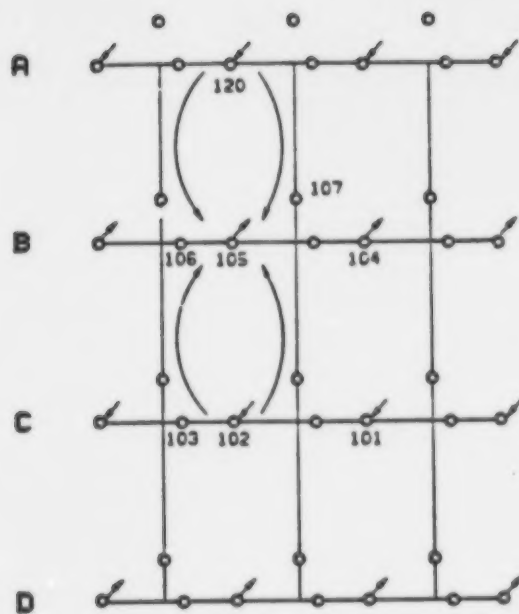


FIG. 4B

James E. Hyman

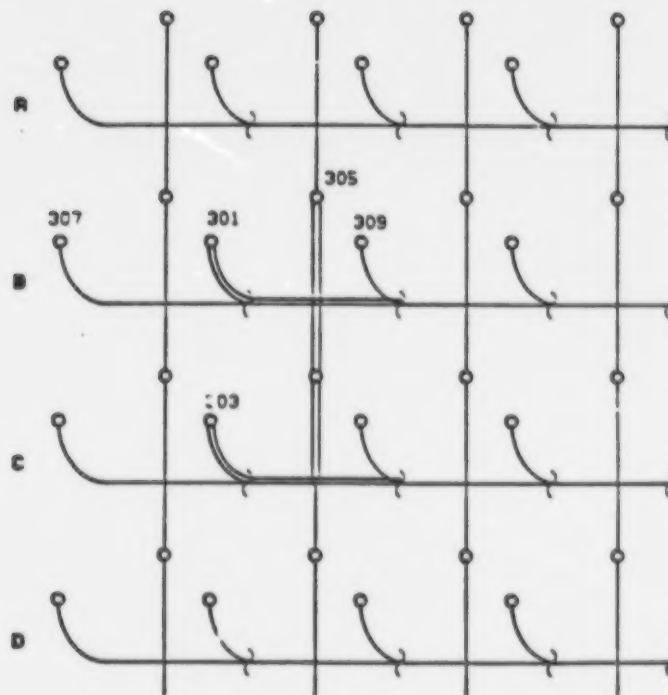


FIG. 5A

John J. Sijden

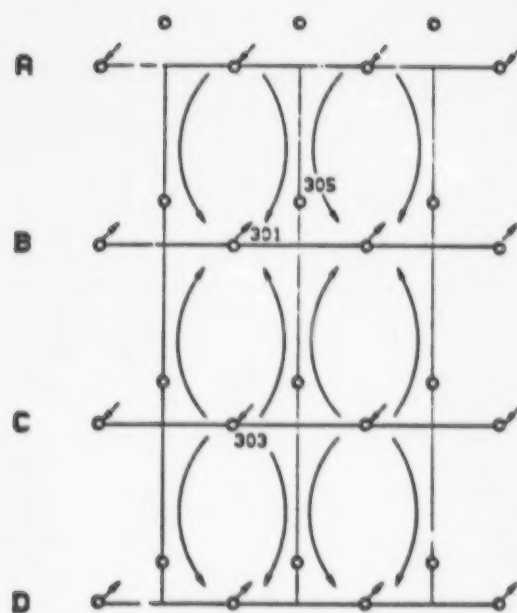


FIG. 5B

Roll of Magnetics

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INFORMATION CENTRE

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(52) Domestic classification
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US 1834235

(58) Field of search
E1F

GB 2 066 333 B

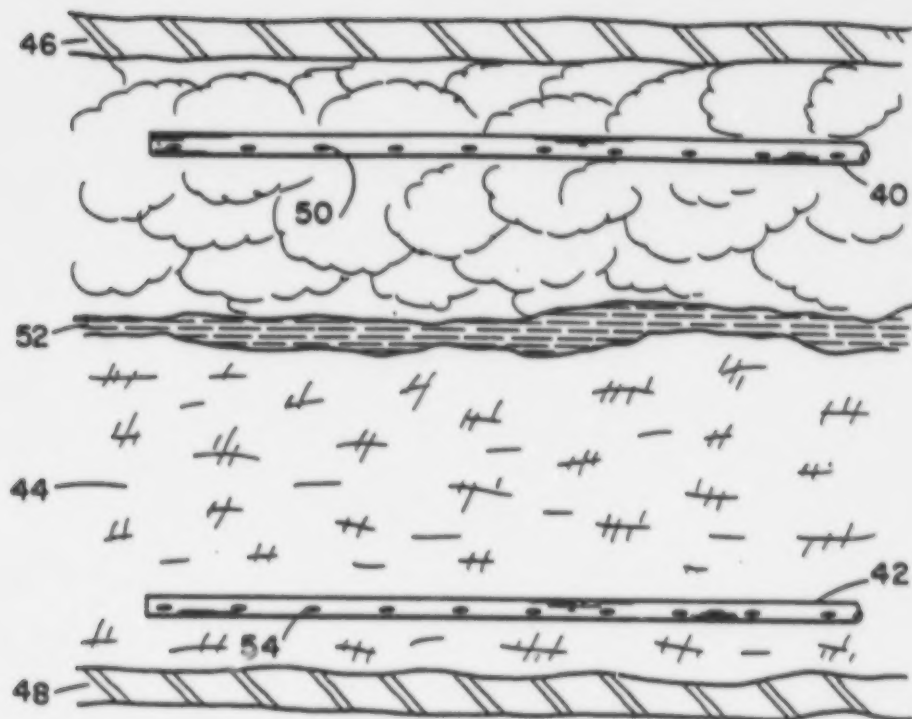


FIG. 3

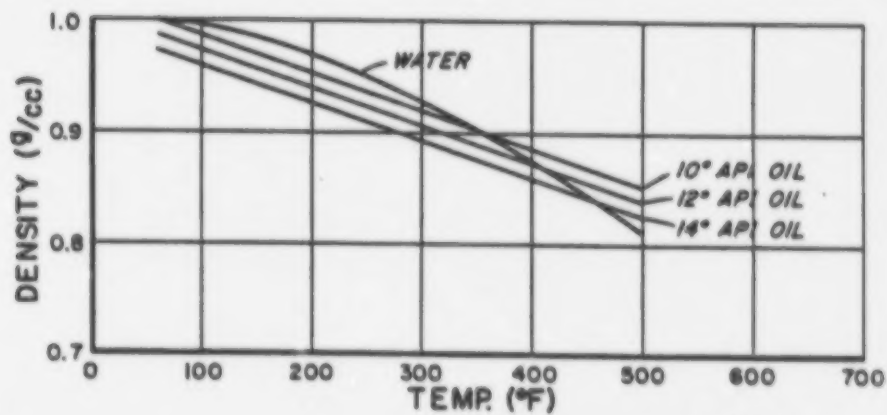


FIG. 4

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METHOD AND APPARATUS FOR RECOVERING HIGH VISCOSITY OILS

This invention relates to methods and apparatus for recovering high viscosity oil from sub-surface earth formations, and more particularly relates to improved methods and apparatus for recovering such oils by employing a large diameter shaft hole and a plurality of drill holes extending radially from the shaft hole.

Early disclosures relating to the recovery of petroleum substances by utilizing a large diameter shaft hole and a plurality of drill holes are provided in U.S. Patent Nos. 1,520,737 and 1,634,235, and a paper published by Ranney in the Petroleum Engineer in 1939 entitled "The World's First Horizontal Hole". These publications propose the drilling of a large diameter shaft into an oil-bearing formation and then drilling radial drill holes into the formation. More recently, U.S. Patent Nos. 4,020,901; 4,099,570; 4,099,783 and 4,160,481 provide improved systems for recovering petroleum substances employing large diameter shaft holes and radials. The above processes, however, suffer limitations relating to restrictions on the rate of introducing the injection fluid, and the overall efficiency of the oil recovery process according to the above techniques may be so poor that recovery of the oil is not economically feasible.

Horizontal drive operations are therefore generally concerned with the "critical velocity" of the injected fluid, so that the driving force does not break down as a result of viscous fingering or gravity override. Since the fluid injected in horizontal drive operations is preferably introduced at rates to keep the driving operation below the critical velocity, the recovery rate, and the corresponding economics of this operation, are often unacceptable.

It is also well-known to inject water via conventional vertical bore holes into the bottom of an oil-bearing formation, while producing oil from conventional vertical bore holes near the top of the formation. In this procedure, often referred to as conventional vertical flooding, the oil is displaced vertically upward by the injected water. By using conventional vertical bore holes terminating near the top of the formation and conventional vertical bore holes terminating near the bottom of the formation, it is also known that low viscosity oils can be collected by injecting a light hydrocarbon in the top of the formation while recovering the light oil from the vertical bore hole terminating at the bottom of the formation. In the latter procedure, the light oil is pushed downward by the lighter hydrocarbon. The recovery of oil utilizing conventional vertical wells and drive techniques are often poor, however, because a limited number of points of recovery are provided by the vertical wells.

The present invention provides in one aspect a method of recovering oil and the like from a subsurface earth formation, comprising the steps of:

5 establishing a shaft hole extending from the surface of the earth to said subsurface formation; drilling a plurality of boreholes substantially laterally from the shaft hole into said subsurface earth formation;

10 drilling a second plurality of boreholes, all terminated substantially at another second level;

15 injecting into said formation through said second plurality of boreholes a displacing fluid to establish a substantially horizontal stratum of said displacing fluid;

20 injecting into said formation through said second plurality of boreholes a driving fluid under pressure to vertically drive said stratum of said displacing fluid through said formation; and

 withdrawing oil from said shaft hole through said first plurality of boreholes while simultaneously injecting said driving fluid into said formation.

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formation and near the bottom of the formation forming chambers to provide increased space for men and equipment. Substantially horizontal drill holes or laterals are thereafter bored radially into the formation. The numbering and spacing of these laterals will be discussed in detail below. For the present, it is significant that one group of laterals is provided near the top of the formation, and another group of laterals is provided near the bottom of the formation. Each group or set of boreholes or laterals effectively blankets a particular portion of the formation, and the configuration of each blanket may be rectangular. Thereafter, drill holes are bored into the face of the formation and radially about the chamber, through which a suitable fluid is thereafter injected into the formation by way of a conduit leading to the surface.

Using the above-described apparatus with one set of laterals near the top of a formation and another set at the bottom of a formation, oil may be recovered by either (a) introducing an injected fluid into the bottom set of laterals while recovering oil from the top set of laterals, or (b) introducing an injected fluid into the top set of laterals while recovering oil from the bottom set of laterals.

The instant invention utilizes a plurality

by using boreholes or laterals within the formation and various "soak" techniques. In the present invention, the driving force of the injected fluid is substantially vertical: vertical upward drive toward the top set of laterals, or vertical downward drive toward the bottom set of laterals. The advantage of driving vertically rather than horizontally, as taught by conventional oil recovery techniques, is that the injected fluid may be introduced at a much higher rate because the likelihood of viscous fingering is substantially reduced and detrimental gravity override is eliminated. A fluid may therefore be injected according to the present techniques at rates equivalent to the maximum output of most commercial generators, without regard to the concept of critical velocity, fingering, or gravity override.

In conventional oil wells, it is often quite difficult to establish a blanket of injected fluid, although the fluid is injected at various points in the plane of the blanket. According to the present invention, the blanket of injected fluid may be more easily established since the fluid is not injected at points in the blanket, but rather is injected along entire lines lying within the blanket. These lines effectively provide a multitudinous number of points of injection so that the blanket for the drive operation is more easily established.

As previously mentioned, the apparatus described may be utilized for vertical upward drive or vertical downward drive. This offers a distinct advantage over the prior art since the injected fluid can be selected for either upward or downward drive depending on the density of the oil in the formation, the desirability of using a miscible or an immiscible injected fluid,

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extend such drill holes to a location adjacent the ends of similar radials extending from an adjacent vertical shaft hole. As will hereinafter be explained in detail, each group of radial drill holes will then define a rectangular pattern within the field, and thus the field may be effectively "covered" with a blanket of such rectangular patterns.

The bore holes or radials may extend from the large diameter shaft hole in a generally horizontal direction. Some of the radials, however, may be positioned at a slight upward angle, e.g., $3^{\circ} - 7^{\circ}$, so that gravity may assist the flow of oil within the lateral. Also, some formations have generally horizontal barrier zones which are impermeable to fluid flow. Relatively thin shale deposits are one example of these impermeable barrier zones. When such zones exist, the bore holes or laterals may be drilled at a greater upward angle, e.g., $10^{\circ} - 18^{\circ}$ upward from the horizontal, so that the bore holes would pass through one or more of these barrier zones. Thus, the recovery of oil and the efficiency of the operation will be increased since oil can be recovered by soak or drive techniques which would have previously remained within the formation because of the presence of the impermeable barrier zones.

It is within the concept of the present invention to locate the radials adjacent the lower limit of the formation, whereby the fluid injected therefrom will also tend to rise as well as travel laterally through the formation, and also to provide additional pluralities of such radial drill holes at other higher locations within thicker formations.

Further features and advantages of the present invention will become apparent from the following detailed description, wherein reference is made to the figures in the accompanying drawings wherein:

5 Figure 1 is a simplified pictorial representation, partly in cross section, of an exemplary installation for recovering oil from a subsurface earth formation according to the present invention.

10 Figure 2 is a cross-sectional representation of a portion of the apparatus depicted in Figure 1.

 Figure 3 is a simplified pictorial representation, partly in cross section, of a portion of the apparatus depicted in Figure 1.

A steam generator 22 at the surface floor provides injection fluid to the upper laterals 14 and 16 by a steam line 24. If desired, a plurality of steam lines 24 may be provided, so that the injected fluid to each upper lateral may be separately controlled at the surface by conventional valving techniques. The lower laterals 18 and 20 may serve as recovery lines for oil, which is collected in recovery tank 26. Each of the lower laterals 18 and 20 may be connected to individual recovery lines 28 and 30 which may terminate at the recovery tank 26, or the recovery lines 28 and 30 may join at a subsurface manifold 32 so that oil from the various lower laterals 18 and 20 flows to the recovery tank 26 by a central recovery line 34.

Referring again to Figure 1, it may be seen that a portion of the radial or lateral 14 extending from the wall of the upper work chamber 10 may be suitably provided with a casing 36, with a perforated portion of the lateral 14 thereafter extending from the casing 36. The walls of the shaft 2 may be conveniently sealed with sections of bolted or welded steel plates to form a casing 38, or may be lined with an appropriate material such as gunite, to prevent caving or other collapse of the walls of the shaft 2. The diameter of the shaft 2 is preferably of a size sufficient to accommodate the passage of men and equipment from the surface 4 to the interior of the work chambers 10 and 12. The mine shaft 2 and each of the work chambers 10 and 12 may be constructed in the manner further described in U. S. Patent 4,160,481.

Both the upper set of laterals and the lower set of laterals depicted in Figures 1 and 2 lie in substantially horizontal planes. As explained in further detail below, the upper set of laterals, in combination with an injected fluid, form a blanket of injected fluid which act as the driving force for the recovery process. Typically, the laterals will radiate from the shaft 2 to enable a substantially horizontal blanket to be established having an area of 25 acres. In Figure 2, the pattern of the blanket formed by the injection radials 14, 15, 16, and 17 is circular. Other configurations are possible, and the particular configuration of the blanket formed by the injection laterals will depend, in part, on the characteristics of the formation, the viscosity of the oil in the formation, the injected fluid, and the possible use of injection laterals in combination with conventional wells. For instance, the configuration of the injection laterals may form a rectangular blanket, as shown in ^{US Pat. Application 2,031,975}, which is hereby incorporated by reference in its entirety. The length of the laterals will depend on their relative position to one another, since the injection laterals preferably function to form a uniform substantially horizontal blanket in a portion of formation 6. Further, the diameters of the laterals will depend primarily upon the type of matrix composing the formation 6, as well as the viscosity of the oil sought to be recovered therefrom.

Figure 3 illustrates a portion of the apparatus generally depicted in Figure 1. A tubular member 40 is typically inserted into any of the boreholes described, such as the laterals 14, 15, 16, and 17 in Figure 2. Likewise, a tubular member 42 may be inserted into the laterals 18, 19, 20, and 21. The oil bearing

Steam from the generator 22 may be injected into upper laterals 14, 15, 16, and 17 by a plurality of steam lines 24. The steam may enter the formation 44 through a series of perforations in the upper tubular members, such as the perforations 50 in the tubular member 40. The perforations 50 may be formed along the entire length of the tubular member 40, and are preferably formed along at least a substantial portion of the length of the tubular members.

Heat from the injected steam will decrease the viscosity of the oil in the formation adjacent the tubular member 40. As the formation 44 is heated, condensate may be formed which will be more dense than the steam, but less dense than the oil in the formation. The steam from the tubular member 40 will, in combination with the steam simultaneously injected in the other upper laterals, produce a blanket of steam generally in the plane of the upper laterals..

Continued injection of steam into the upper laterals will cause a pressure increase in the top of the formation 44. This pressure increase will drive the oil in the formation downward toward the lower tubular member 42. Also, the condensate from the injected steam may serve as a face for the driving force. In other words, the increase in pressure above the condensate layer will force the condensate layer downward, thus driving the oil downward from the formation.

As the steam is injected in the upper tubular member 40, oil will be simultaneously recovered through perforations 54 along a substantial portion of the length of the lower tubular member 52. Referring to Figure 2, steam injected into the upper laterals 14, 15, 16, and 17 will drive the oil downward for

pressure at the place of injection is generally limited for safety reasons to 1 psig per foot of overburden. For instance, if steam is injected into the laterals 14, 15, 16 and 17 which are 400 feet below the surface 4, it may be desired to limit the pressure provided in the upper portion of the formation 6 to 400 psia.

As previously mentioned, vertical drive may be properly utilized without concern for gravity override, even with injection rates far exceeding the injection rate employed in conventional horizontal drive. In the embodiment described above, the density contrast between the oil and the injected fluid is deliberately utilized during the driving operation to increase the efficiency of the recovery processes, while the same density contrast may result in gravity override in horizontal drive operations which is detrimental to the efficiency of horizontal drive recovery processes. Also, since the oil is being driven vertically downward, the likelihood of viscous fingering during the driving operation is substantially eliminated since (a) a uniform blanket of driving fluid is initially formed, (b) the condensate layer 52 acts as a face for driving the oil from the formation, and (c) the oil is being driven vertically downward, and the injected fluid will not tend to pierce through the formation 44 because the injected fluid is less dense than the oil below the injected fluid. Further, as explained below, viscous fingering prior to the driving operation increases the efficiency of the recovery process according to the present invention, rather than being detrimental to the recovery efficiency as in horizontal drive techniques.

upper laterals 15 and 16, while steam is not injected into the upper laterals 14 and 17. Thus, oil recovery would continue from the lower laterals 18, 19, and 20, but oil recovery from the lower lateral 21 would be effectively discontinued.

An alternative procedure that may be used when steam or condensate is recovered in one of the plurality of lower laterals is to inject cold water into the lower lateral while continuing steam injection into the upper laterals. Referring to the example described immediately above, if water or condensate is being recovered from the lower lateral 21, cold water may be injected into lower lateral 21 while continuing to inject steam in either upper laterals 15 and 16 or all the upper laterals 14, 15, 16, and 17. The introduction of the cold water into the lower lateral 21 effectively terminates the recovery of any fluid from the lateral 21, thus the steam injected into the formation would be effectively used to produce oil from the laterals 18, 19, and 20.

One of the advantages of the plurality of upper laterals 14, 15, 16, and 17 is that a blanket can be easily and rapidly established in the formation which will enhance the driving efficiency of the injected fluid. The rapid establishment of a blanket in the formation will increase the thermal efficiency of the recovery process since less heat and injection fluid will be lost to adjacent beds or escape from the formation entirely. Conventional vertical injection wells do not result in the rapid and efficient establishment of a blanket, since the fluid is injected at points within the plane of the blanket. According to the present invention, the laterals lie within the plane of the blanket to be established, and thus lines of injection are provided rather than

the injection fluid tends to spread out evenly through the formation and increase the sweep efficiency of the recovery process. If the upper laterals were to be placed directly above the lower laterals, there is less likelihood that the oil near the bottom of the formation and between the lower laterals would be recovered.

As previously described, the use of upper and lower laterals within a formation enables a blanket to be easily formed for the driving process. It is possible to use conventional vertical injection wells instead of the injection laterals, although the blanket of driving fluid may not be established as readily as if horizontal boreholes or laterals were used for the injectors. Referring to Figure 5, there is illustrated another form of my invention which employs the use of conventional vertical wells 60 and 62. It will be seen that these conventional vertical wells 60 and 62 are drilled from the surface 64 through the top rock layer 66 and terminate in the upper portion of the formation 68. Fluid may be injected into the vertical wells from a common generator, or separate generators 70 and 74 may be employed for each vertical well. Valves 72 and 73 may be used to control the flow of fluid from the generators to the formation.

The laterals 76 and 78 extend radially from the work chamber 80 in the lower portion of the mine shaft 82. The lower set of laterals preferably "blanket" a portion of the formation, as previously described. Valves 83, 84 and 86 may be used to control the recovery of oil from the laterals to the recovery tank 88. In Figure 5, both the laterals 76 and 78,

vertical and horizontal injections, and this may be desirable if only a relatively few number of injection laterals are utilized.

To assist in establishing a horizontal blanket if vertical injectors are used in combination with recovery laterals, fluid may be initially injected into a portion of the vertical boreholes while oil is recovered from the remaining vertical boreholes. Thus, fluid may initially be inserted into the odd-numbered vertical wells, and the oil may be driven horizontally and recovered by the adjacent even-numbered vertical boreholes until the injection fluid is recovered in the adjacent even-numbered vertical boreholes. At this point, a horizontal blanket of injection fluid is established, and fluid may be injected in all the vertical boreholes 102 through 109 to drive the oil downward for recovery by the lower laterals 112 through 119. In this embodiment, the vertical boreholes are preferably spaced between the injection laterals and toward the periphery of the blanketed zone to increase the efficiency of the recovery operation. As previously described, it is within the concept of this invention to drive vertically upward or vertically downward, and the conventional vertical boreholes herein described may terminate near the top of the formation if downward drive is desired, or may terminate near the bottom of the formation if upward drive is desired.

It is within the concept of this invention to employ a plurality of substantially horizontal laterals and inject fluid to drive the oil in the formation vertically toward recovery laterals. Oil may be driven vertically upward or downward, and

having a lower density than the previous slug, may thereafter be injected into the formation. Finally, a gas may be injected. The injecting slugs of fluid and gas produce a driving force, and the solvent first injected acts as the face of the driving force. This technique, which may be referred to as graded miscible displacement, may be highly effective, permit much higher injection rates, and yield higher production rates than possible according to the prior art.

The density of the injection fluid may vary with temperature changes to a different extent than the oil in the formation. It is possible, therefore, to inject a particular fluid in the top laterals as a driving force when that fluid is lighter than the oil, and to inject the same fluid in the lower laterals as a driving force when the fluid is heavier than the oil in the formation. Referring now to Figure 4, there is depicted a chart which illustrates the approximate density of the water, 10° API oil, 12° API oil, and 14° API oil as a function of temperature. It will be noted that at 100° F. ^(37° C.) water is denser than 12° API oil, but that at 500° F. ^(260° C.) 12° API oil is denser than water.

The principle of different density changes for fluids can be fully utilized according to the present invention. For example, high temperature steam can be injected into the upper laterals, and 12° API oil can be recovered by the lower laterals. At the pressure within the formation, the condensate ^{from the} _(260° C.) high temperature steam may form a layer of water at 500° F. _(260° C.) In this case, both the steam and the condensate are lighter than the oil, and can be efficiently used to drive the oil downward. After steam or condensate has been recovered from one of the

driving in the reverse direction will cause the driving fluid to invade some areas that may have been sheltered from the forward driving fluid. Also, the injection of cold water in the lower laterals, as described above, may cause some water to flash to steam because of the residual heat in the formation, and the steam may lower the viscosity of some remaining oil to enhance the effectiveness of the upward driving process.

In the methods described above, oil recovery is based on a vertical drive process, which may be simplistically described as injecting the fluid in one set of boreholes while recovering oil from another set of laterals. It is within the concept of my invention, however, to improve the efficiency of the vertical driving process by providing for a limited soak cycle for each of the sets of laterals. For instance, if a vertical downward drive of the oil is to be achieved, it may be initially desirable to inject steam in the lower laterals to soak the formation directly adjacent the lower laterals and thus improve the subsequent driving process. Also, the upper laterals may be thereafter injected with steam to soak the formation adjacent the upper laterals and therefore enhance the uniformity of the driving blanket. After the lower laterals have been opened and oil begins to flow in the lower laterals, steam may thereafter be injected in the upper laterals to drive the oil toward the lower laterals.

Soaking the formation about the upper and lower laterals prior to establishing the driving process, as described above, may be beneficial in most applications. If a high viscosity oil

have a greater area than that commonly associated with horizontal driving techniques. For instance, when conventional horizontal drive between vertical wells is utilized in a formation 60 feet thick, the area or face of the driving formation is typically approximately 12,500 square feet per acre. If vertical drive is practiced between horizontal laterals according to the present invention, the area or face of the driving front increases to approximately 43,000 square feet per acre. Thus, if the same injection rate per area of driving front is utilized, fluid is injected at approximately 3.5 times the rate as in conventional horizontal drive. Moreover, since the oil is being driven vertically rather than horizontally, the injection rate per area of the driving front may be substantially increased since viscous fingering is substantially eliminated during the driving operation.

The larger driving face area, therefore, enables more driving fluid to be injected into the formation while maintaining a relatively low, stable driving velocity across the formation. Also, as previously mentioned, the driving velocity may be substantially increased when compared to horizontal drive since vertical driving minimizes the likelihood of viscous fingering. Further, the fluid may be injected at higher pressures and at higher rates than realized in the prior art, which improves the efficiency of the recovery process. For instance, steam which may have been injected at 25% quality in horizontal drive operations may effectively be injected at the higher rates and with greater steam quality, e.g., 80%, than in the prior art. Also, as previously mentioned, superheated steam may be used as the injection fluid.

conventional vertical wells 102 through 109 may be used to inject air or oxygen. Thus, in situ combustion may thereafter be utilized to drive the oil downward for recovery by the laterals or boreholes 112 through 119. If desired, this latter operation may be conducted in rotating segments, rather than exploiting the entire area at one time, which would reduce the capital investment required for the air or oxygen compressors.

Alternatively, in situ combustion may be conducted in the upper portion of the formation between conventional vertical wells, as previously described, and thereafter another fluid such as water, steam, inert gas or mixtures thereof injected into all the vertical wells for driving the oil downward for recovery by the horizontal laterals. If desired, the lower horizontal laterals may be initially steam soaked or soaked at intervals during the driving process to maintain the desired recovery flow. The in situ combustion between the conventional vertical wells may be conducted until enough heat has been added to the formation for an efficient oil recovery by subsequent vertical drive techniques. If water is injected into the formation as the driving fluid from the vertical conventional wells, the residual heat from the "burned out" zones may generate steam in situ which may efficiently drive the remaining oil downward for recovery by the laterals.

The above operation is especially attractive from an economic standpoint since little or no surface fuel is used to heat the formation. Temperatures in the combustion zone may be 800° F. ^(425-825° F.) to 1000° F. or more, and very good drive of heavy oil can be ^(125-147° F.) achieved if the oil in the formation is heated to 250° to 300° F. Also, creating a blanket of combustion-cleaned matrix establishes

shafts and laterals, as described herein. Also, by operating such multiple installations in a simultaneous manner, as more fully described in ^{UK Patent 2,031,975}

an entire field may be drained in a systematic manner.

It may be that two or more oil bearing formations exist at different elevations. In such a case, it is within the concept of my invention that a vertical mine shaft may be employed, and upper and lower laterals may extend from the mine shaft into each of the oil bearing formations.

As hereinbefore described, the techniques of the present invention are principally directed to recovery of relatively heavy oils. However, it should be noted that these techniques are not limited to heavy oils only, but can be used with substantial effect in recovering hydrocarbons of various weights and gravities.

Other alternate forms of the present invention will suggest themselves from a consideration of the apparatus and practices hereinbefore discussed. Accordingly, it should be clearly understood that the systems and techniques depicted in the accompanying drawings, and described in the foregoing explanation, are intended as exemplary embodiments of my invention, and not as limitations thereto.

4. The method described in claim 3, wherein the gas comprises substantially air, oxygen, hydrogen, carbon dioxide, inert gas, stack gas, natural gas, ethane, propane or butane.

5 5. The method described in claim 2, further including the steps of:

 monitoring recovery of said driving fluid from each one of said first plurality of boreholes; and

 injecting a fluid comprised substantially of water
10 through selected ones of said first plurality of boreholes in accordance with withdrawal of said driving fluid from each one of said first plurality of boreholes in order to prevent further withdrawal of said driving fluid.

 6. The method described in claim 2, wherein another
15 driving fluid is injected through said first plurality of boreholes into the formation in order to vertically drive the oil towards said second plurality of boreholes; and

 withdrawal of oil from said second plurality of boreholes while simultaneously injecting said second driving
20 fluid into said formation.

 7. The method described in claim 2, further including the steps of:

 injecting the displacing fluid through said first plurality of boreholes into said formation until said fluid
25 reaches at least one of the second plurality of boreholes;

 thereafter injecting said driving fluid through said second plurality of boreholes into said formation;

recovering oil from said first plurality of boreholes while simultaneously injecting said driving fluid into said formation.

13. The method described in claim 12, further including the steps of:

measuring oil production from each one of said second plurality of boreholes; and

controlling the injection of said driving fluid through selected ones of said first plurality of boreholes depending upon production of oil from each one of said second plurality of boreholes.

14. The method described in claim 9, wherein the step of injecting said driving fluid also includes:

establishing at least 100 psi (7 kg/cm²) pressure difference between said first and second pluralities of boreholes by injecting said driving fluid; and

vertical driving of oil towards said second plurality of boreholes.

15. The method described in claim 9, further including the steps of:

injecting said displacing fluid into said formation through said second plurality of boreholes until said displacing fluid reaches at least one of said first plurality of boreholes; and

injecting said displacing fluid which precedes the injection of said driving fluid into said formation.

18. Apparatus as defined in claim 16, wherein said first plurality of boreholes lies in a substantially horizontal first plane in an upper portion of said formation, each of said second plurality of boreholes extends from
5 said surface of the earth and terminates at said second elevation in a lower portion of said formation, and said injection means comprises means for injecting a displacing fluid more dense than said oil.

19. Apparatus as defined in claim 16, wherein each
10 of said second plurality of boreholes extends radially from said shaft.

20. Apparatus for recovering high viscosity oil from subsurface earth formations, substantially as herein described with reference to Figures 1 and 2, or Figures 5
15 and 6, of the accompanying drawings.

21. A method of recovering high viscosity oil from subsurface earth formations, substantially as herein described with reference to the accompanying drawings.

The text of the specification has been reproduced by photocopying the applicant's original typescript. It may contain a few amendments which are difficult to read. The original typescript containing these amendments may be inspected on the premises of the Patent Office

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US Patent 4,437,706



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(19) (CA) CANADIAN PATENT (12)

(54) HYDRAULIC MINING OF TAR SANDS

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(73) Granted to Gulf Canada Limited
Canada

(21) APPLICATION No. 382,912

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Canada

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This invention relates to a method for recovering bitumen from unconsolidated bitumen-bearing formations including tar sands by hydraulic mining.

5 Petroleum is found in underground deposits or reservoirs from which it can in many cases be recovered by allowing it to flow to wells drilled into the reservoir, whence it can be pumped to the surface. Some reservoirs contain petroleum which is too viscous to flow toward the wells at an economic rate. These include the types
10 known as heavy oils. Other reservoirs, on the other hand, contain petroleum that will not flow at all at ambient temperatures, including the petroleum found in the Athabasca tar sands in Alberta, Canada. This type of petroleum is known as bitumen, and a number of techniques have been developed in attempts to recover it economically. The only
15 methods used in commercial operations to date are surface mining methods, wherein the overburden is removed and the tar sands broken up by mechanical action into pieces capable of being put through an extraction process using hot water to separate the bitumen from the other materials in the tar sands. Surface mining is limited to areas
20 where the overburden is thin enough that it can be economically removed, putting about 90% of the bitumen contained in the tar sands out of economic reach. Where the overburden is too thick for economic removal, in-situ methods are used, in which wells are sunk from the surface to reach the zone containing the bitumen in
25 combination with sand, clay or other minerals. In the well-known steam stimulation process, a combination injection/production well is drilled, and steam is injected into the reservoir in order to reduce

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the viscosity and increase the flowability of the bitumen, which can then be pumped out. A modification called the steam drive process uses separate injection and production wells and the flow of steam assists the flow of bitumen by creating a pressure gradient as well as reducing its viscosity. Both processes are extravagant in their use of energy, requiring about 12 gigajoules of energy input to recover one cubic metre of bitumen with a heating value of about 42 gigajoules.

Hydraulic mining methods have been proposed to overcome the necessity of removing the overburden. Several proposals have involved the driving of tunnels beneath the reservoir. An early invention was that of Laughlin, USP 1,936,643 (1933), which disclosed the projection of hot water upwardly through fixed pipes spaced at intervals along a tunnel. The tar sand was loosened and allowed to fall into the tunnel whence it was removed to a separation plant. Lambly et al, USP 3,934,935, disclosed a method using jets to loosen and create a slurry of tar sand which flowed downwardly and was removed to a separation plant through pipes placed in tunnels underlying the reservoir. The invention of Redford, USP 3,951,457, was a method operable from the surface. Redford disclosed a technique using an injection string equipped with a drill bit at its lower end and having horizontal jet streams directed at the tar sand deposit. The jets could be rotated with the injection string, loosening the deposit which was pumped as a slurry to the surface where the bitumen separated from the sand and water in a settling tank. A non-condensable gas was injected to provide a gas-filled cavity so that the jets reached deeply into the cavity.

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In any technique not providing a gravity drain for produced slurry, unless gas pressure is provided to depress the liquid below the path of a jet, there still remains the problem that the effectiveness of the jet extends only a short distance from the nozzle. This problem is overcome by the present invention which provides a movable jet. Accordingly, the invention consists in a method of recovering bitumen from unconsolidated bitumen-bearing formations including tar sands, comprising:

- (a) introducing into said formation at least one nozzle projecting a jet of aqueous hydraulic mining fluid at high velocity towards said formation, said jet having a forward component;
- (b) bringing said nozzle into proximity with said formation, said jet impinging thereon with sufficient velocity to erode said formation and substantially separate said bitumen from other components thereof;
- (c) advancing said nozzle towards said formation as it erodes to separate further quantities of bitumen; and
- (d) recovering said separated bitumen.

The invention further consists in an apparatus for recovering bitumen from unconsolidated bitumen-bearing formations, comprising:

- (a) at least one nozzle, adapted to discharge a jet of hydraulic mining fluid towards an erodable face of said formation, thereby separating said formation into a bitumen-rich material and a sand-rich material;

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- (b) means adapted to move said nozzle towards said face as it erodes; and
- (c) recovery means adapted to recover said bitumen-rich material separately from said sand-rich material.

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In the present invention, the jet provides rapid erosion of the formation without the need for removing the mining fluid from the jet's path by being advanced continually towards the eroding face of the formation. The jet can be placed on rigid or flexible tubing, or tubing comprising both rigid and flexible sections. A single jet can be employed, producing a relatively narrow borehole if it is advanced in a linear path, or producing a wide cavity if it is allowed to sweep from side to side across the axis of the rigid part of the tubing. The jet can point in an axial direction relative to the tubing, or it can discharge at an angle to the tubing axis; such angle can range up to about ninety degrees. A plurality of jets can be employed, spaced so as to complement one another, acting in a single direction or in more than one direction. It is necessary that there be some forward component to the jet to aid in its forward penetration of the formation, because a jet with no forward component erodes a wide but not deep hole. The forward component can advantageously comprise at least one jet having a forward angle, or it can comprise a plurality of jets, at least one of which projects with a forward component and at least one projects laterally. The jet impinges on the face of the bitumen-bearing formation with a velocity high enough to erode the formation and to separate a bitumen-rich material from the sand which makes up the bulk of the formation, and as the face moves away from the jet because of erosion.

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the jet is advanced continuously or stepwise towards the face, continuing the erosion and separation.

The hydraulic mining fluid can be water with no additives.

5 It can be cold water, but is preferably at least at the same temperature as the formation and most preferably is at least 60°C for best separation of the bitumen-rich material from the sand. Any gases naturally dissolved in the mining fluid tend to release with the release of pressure at the nozzle, and to aid in flotation of the
10 bitumen. Optionally, additional gas can be dissolved in the mining fluid to increase the flotation effect. The density of the mining fluid can optionally be increased to aid in floating the bitumen by dissolving one or more solids in it, preferably inorganic salts, for example sodium chloride, which is inexpensive and readily available,
15 and which can raise the density of an aqueous mining fluid sufficiently to float any known bitumen. Optionally, the mining fluid can include a surfactant to aid in separation of clays that may be entrained in the bitumen.

20 The several configurations of nozzle and flexible or rigid, straight or curved tubing can be used in various combinations sequentially on the same borehole. For example, it may be desirable to switch from a rigid to a flexible tubing during the mining of a cavity.

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The invention will now be further described by way of example only and with reference to the drawings in which:

Figure 1 shows a preferred embodiment of the invention, in which a single jet nozzle moves in a single axis in an in-situ operation;

Figure 2 shows a variation of the embodiment of Figure 1 wherein the nozzle moves in more than one axis;

Figure 3 illustrates a variation of the embodiment of Figure 2 which can bore an essentially horizontal passage and open a cavity remote from the wellhead.

Figure 4 illustrates a surface mining operation incorporating a multiple-jet device allowing an increased production rate of bitumen-containing slurry; and

Figure 5 illustrates an elevation of a surface mining operation using the multiple-jet device.

In Figure 1, there is illustrated a travelling jet which dislodges the matrix in which the bitumen is trapped. The surface being attacked continually breaks away and as it does so the jet is advanced towards the eroding face, breaking away more of the matrix and continuing until the extremity of the pay zone is reached. Hydraulic mining fluid 15 is introduced into tubing 5 under pressure and issues through nozzle 12 as jet 11. The overburden 2 can be drilled if desired, or optionally it can be bored using the hydraulic jet itself. When the overburden 2 has been penetrated a casing 6 can be set, in order to minimize the erosion of material from the overburden layer as produced slurry 16, comprising bitumen, sand, and water, passes by on its way to the surface. The casing need not be taken below the overburden 2 because any enlargement of annular space 14 in bitumen-containing zone 1 would be advantageous as it would produce bitumen,

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provided the enlargement was not so great as to cause collapse of the overburden. As jet 11 begins to erode face 13 of the bitumen-containing zone 1 directly in front of it, new surface is exposed farther away from jet 11. As is well known in the art, the force of a submerged jet of liquid decreases rapidly with increasing distance from the nozzle; therefore the rate of erosion of face 13 rapidly falls off if nozzle-to-face distance increases. Tubing 5 is relatively long and permits nozzle 12 to be advanced in order to remain close to face 13 as face 13 is eroded by the action of jet 11, moving as far as the extremity of bitumen-containing zone 1, all the while maintaining pressure of the hydraulic mining fluid. Any suitable equipment may be used for advancing the tubing and feeding fluid. Preferred devices are of the general class termed "reeled-tubing units", which are commonly used for oil well maintenance work, and which use tubing that is effectively rigid and straight when off the reel. It is generally convenient to advance nozzle 12 at a rate as high as the maximum rate of erosion of face 13 will allow. The produced materials in slurry 16 are carried upwards in the annular space 14, emerging above ground surface 3 in aboveground casing 7 from which they flow into settling zone 4, where the materials settle in order of density. Where the hydraulic mining fluid is of intermediate density, the sand 19 settles to the bottom of settling zone 4, hydraulic mining fluid layer 18 is intermediate and bitumen layer 17 rises to the top. The high degree of separation obtained is due to the action of jet 11 at face 13, which not only loosens small pieces of bitumen-sand matrix but also frees the bitumen from most of the associated sand particles that make up the larger part of the matrix. The sand that is separated constitutes the

bulk of the material in the bitumen-containing zone and when it is removed, the bitumen is in condition for further processing. The separated sand can be replaced in the excavation by suitable means, thereby minimizing the disposal problem.

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In Figure 2, another embodiment of the invention is illustrated in which a large cavity is created in the formation by the action of jet 41. This is accomplished by providing the jet 41 with a lateral force component by drilling nozzle 42 slightly off-axis relative to tube 5, or by imposing a small curvature 46 on the leading section of tube 5 or by other suitable means. Nozzle 42 advances along the path cleared by jet 41 and, in the absence of any rotary motion of the tube, describes an arc representing the circumference of a circle in a vertical plane with a radius determined by the relative magnitudes of the axial and off-axis force components. This radius must be large enough so that a tubing possessing sufficient flexibility will impose no significant frictional force on the slightly curved hole boundary.

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After a relatively short advance in a generally downward, but slightly curved path, the advance is reversed and a rotary, or a limited oscillatory, motion is imposed on the tubing at the surface by means known in the art. Tubing 5 is then advanced and jet 41 thus sweeps a wider conical space instead of the narrow cylindrical volume of the embodiment shown in Figure 1. The sequence is repeated so as to enlarge the conical space. As the cavity increases in size, the tubing is subject to reaction forces tending to drive it across the diameter of the cavity so that the central portion is also cleared. This motion

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can be further controlled by cyclical changes of jet pressure between an upper and lower limits. By repeated rotations of the tubing as the face erodes, bitumen can be produced from a large cavity 49 in bitumen-bearing zone 1.

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Figure 3 shows an adaptation of the embodiment shown in Figure 2 which is controllable and capable of drilling a hole in a generally horizontal direction. As described in relation to Figure 2, an off-axis force component in jet 51 causes the nozzle 52 to follow a circular arc in the absence of an imposed rotation. With an imposed rotation, or controlled oscillation, the nozzle advances along a generally helical path 53, 54 to a chosen position in the formation. In this location, a cavity 50 can be formed in the bitumen-bearing zone 1 by the same process as described in relation to Figure 2.

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In a large cavity most of the sand remains in the cavity because the upward velocity of the returning fluid 16 is below the critical fluidization velocity of the sand particles. At the end of the production operation, a tube or hose can be substituted for the jet device and a sand slurry pumped from the reclaim area at the surface to the cavity until returning sand at the surface signals that the cavity has been filled to capacity with sand. Optionally, several cavities can be eroded and the bitumen produced, using a single well.

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Figure 4 illustrates an embodiment of the invention in a surface mining operation on a large scale. Jet plate assembly 25 includes a plurality of nozzles 23 facing downwards which are supplied with hydraulic mining fluid 15 through supply pipe 20. Jets 21 issue

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from nozzles 23 eroding face 27 of the bitumen-containing zone 1 in an area approximately as large as the area attacked by the jets. The nozzles are disposed over the underside of the jet plate assembly in such a manner that the area eroded by each jet is contiguous with or
5 slightly overlaps the area eroded by the adjacent jet at the selected conditions of hydraulic mining fluid density and pressure, and of jet geometry. The nozzles can conveniently be arrayed in a square arrangement, that is, an arrangement wherein each nozzle is equidistant from its four nearest neighbours and wherein a line drawn through two
10 of its nearest neighbours and itself is perpendicular to a line drawn through the other two of its nearest neighbours and itself. A square arrangement is preferred where the nozzles have a square spray pattern. In cases where round-pattern nozzles are used it is preferable to set up the nozzle array in a hexagonal arrangement, i.e. in an array in
15 which each nozzle is equidistant from its six nearest neighbours, thus providing complete spray coverage with minimum overlap. Optionally, the jets can include a lateral component in their spray patterns. The plate assembly 25 can optionally be rotationally moved in a lateral plane to move the nozzles past the eroding surface, providing a uniform
20 spray coverage. The hydraulic mining fluid pressure in the supply pipe 20 can be varied to suit the conditions. Within limits, the spray pressure required to dislodge and separate the sand from the bitumen is proportional to the forces binding the two components. Higher pressure requires greater energy to drive the hydraulic mining fluid. As noted
25 above, it is known that the effectiveness of submerged hydraulic jets falls off rapidly with increasing distance from jet to eroding face; the rate of advancement of the jet plate assembly is adjusted so that

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the rate of erosion of the face equals the rate of advance. The jet plate assembly is rigidly supported in order to control its horizontal and vertical position during lowering and raising of the assembly.

5 Produced slurry 24 containing bitumen, sand and hydraulic mining fluid passes through plate 25 via return holes 26; the return holes 26 pass upwards through plate 25 adjacent to, but not in contact with, the plenum supplying nozzles 23.

10 In a field production operation, an embodiment having a jet plate assembly can be used as shown in Figure 5. It is advantageous to remove the overburden prior to starting the operation. A travelling lake is depicted wherein the jet plate assembly 25 is advanced to a level no lower than the depth of the bitumen-containing zone 1 in successive channels. After the jets erode and produce the bitumen and
15 sand in one channel 31, the jet plate assembly is raised and moved approximately the amount of its width, then advanced into adjacent channel 32. The plate assembly can be advanced in a direction either vertical or at an angle to the vertical, the selection of angle being related to, inter alia, the conditions at the mining site. Produced
20 sand separates from bitumen and returns to the pay zone as sand fill 33. The sand is carried in a generally upward direction by the rising water. Directly above the plate the sand is in a fluidized condition. Outside the fluidized region the sand can settle to form inclined sand surface 36. The height of the pile of returned sand 33 can be varied
25 by a mechanical device to suit the needs of the operation of jet plate assembly 25. Produced material 34 comprises bitumen in a top layer, hydraulic mining fluid in an intermediate layer, and sand in a bottom

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layer, providing the density of the hydraulic mining fluid is between that of the bitumen and that of the sand. The produced sand usually occupies a greater volume than the same mass of sand in the undisturbed state, and there may thus be a small surplus of sand to be disposed of at the surface after the underground space occupied by the bitumen-containing sand is refilled with produced sand. If there is no overburden at the site, all of the produced sand can be moved by a suitable device and replaced, raising the level of the surface slightly until settling occurs.

Example

The following example is illustrative of the process and is not intended to restrict the scope of the invention.

A sample of mined tar sands material taken from the Surmont deposit in Alberta was packed into a test cell to simulate in-situ conditions. The 120 ml capacity vessel was a pressure gauge sight glass comprising a steel frame, two of whose sides were of heavy glass material permitting viewing of the contents. The top of the test cell was fitted with a small vertical containment tube from the side of which led a downwardly sloping conduit. A catch vessel at the bottom of the conduit trapped the material produced from the test cell. A water storage vessel contained a supply of water kept at an appropriate temperature, and was equipped with a thermocouple, auxiliary heater, and a sealed top capable of containing a controlled pressure sufficiently high to produce a jetting action from a 1.6 cm outside diameter stainless steel tube 40 cm long, connected to the bottom of

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the storage vessel by flexible pressure tubing through a shut-off valve. With water heated to 80°C under a nitrogen pressure of 3.55 MPa (absolute) and moderate downward manual force, the tube penetrated to the bottom of the tar sand pack in approximately two seconds with very little resistance, travelling a distance of about 30 cm downwards. A slurry of injected water and tar sand overflowed into the catch vessel; the slurry immediately separated into three layers: sand, cloudy water and bitumen-rich material. From the cloudy water layer a slowly-settling material gradually separated, leaving a relatively clear water layer. The relative amounts were sand, 10 ml; slowly-settling material, 6 ml; water, 130 ml; and bitumen-rich layer, 10 ml.

The present process is useful in the recovery of oil sands bitumen. It is capable of easily separating bitumen from sand in oil sands that are susceptible to the hot water process. Further, it is clear that the jet action causes the separation at the surface being attacked, thus making it feasible to leave a substantial portion of the sand underground and produce mainly the water and bitumen. Even if sand is produced, an important advantage is that substantially all of it can be reinjected into the well after completion, thus minimizing the disposal problem. Another advantage of the present invention is that the advancing jet erodes the surface of the reservoir without the necessity to surround the jet with a gaseous medium. A further advantage of the present invention over steam processes is its relatively high energy efficiency. Because the maximum temperature to which the reservoir is heated is only about 100°C, compared to up to

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300°C using steam, the thermal losses are much lower. Combined with the energy required for pumping, the present process uses about one-eighth to one-fifth the energy required for steam processes.

5 An advantage of aqueous hydraulic mining fluid over hydrocarbon solvents is that any of the fluid that evaporates or escapes from the system does not cause environmental damage. Any makeup fluid that is added to compensate for losses costs much less than hydrocarbon solvents; in addition, the volume lost to evaporation
10 is lower than that of volatile solvents. Because water does not dissolve substantial quantities of bitumen, the mining fluid can easily be separated for recycling.

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What is claimed is:

1. A method of recovering bitumen from unconsolidated bitumen-bearing formations including tar sands, comprising:
 - (a) introducing into said formation at least one nozzle projecting at least one jet of aqueous hydraulic mining fluid at high velocity through a liquid medium towards said formation, said jet having a forward component;
 - (b) bringing said nozzle into proximity with said formation, said jet impinging thereon with sufficient velocity to erode said formation and substantially separate said bitumen from other constituents thereof;
 - (c) advancing said nozzle towards said formation as it erodes to separate further quantities of bitumen; and
 - (d) recovering said separated bitumen.
2. A method as claimed in Claim 1, wherein a plurality of nozzles is simultaneously brought into proximity with and advanced towards said formation.
3. A method as claimed in Claims 1 or 2, wherein said bitumen-bearing formation is tar sand.
4. A method as claimed in Claim 1, wherein said nozzle is attached to a tubing of sufficient flexibility to allow the end of said tubing to which said nozzle is attached to describe an arcuate motion when said fluid is issuing under pressure from said jet, and to cause said jet to erode said formation over an arcuate area.

5. A method as claimed in Claim 4, wherein said tubing is rotated simultaneously as said nozzle erodes said formation over an arcuate area, whereby a cavity is created whose diameter is large in comparison to the diameter of said nozzle.
6. A method as claimed in Claim 1, wherein said fluid comprises water.
7. A method as claimed in Claim 6, wherein the temperature of said water is at least equal to the formation temperature.
8. A method as claimed in Claim 6, wherein the temperature of said water is at least 60°C.
9. A method as claimed in Claim 6, wherein said fluid comprises water and at least one dissolved solid which raises the density of said fluid.
10. A method as claimed in Claim 9, wherein said dissolved solid comprises an inorganic salt.
11. A method as claimed in Claim 9, wherein said dissolved solid comprises sodium chloride.
12. A method as claimed in Claim 6, wherein said fluid comprises water and a surface active agent.
13. A method as claimed in Claim 6, wherein said fluid further comprises a dissolved gas.

14. A method as claimed in Claim 4, wherein said tubing comprises a rigidly curved portion adjacent said nozzle, further comprising the steps of:
- (a) withdrawing said nozzle from said eroding face;
 - (b) rotating said tubing and nozzle; and
 - (c) advancing said nozzle towards a second portion of said eroding face, said steps being carried out repeatedly and in sequence to create a substantially conical cavity.
15. A method as claimed in Claim 14, wherein said tubing is simultaneously advanced and rotated, whereby said nozzle advances in a substantially helical path.
16. A method as claimed in Claim 15, wherein said tubing is simultaneously advanced and rotated through a defined angle, and said tubing is further simultaneously advanced and rotated back through a substantially equal angle, causing said nozzle to advance in a substantially predictable direction.
17. Apparatus for recovering bitumen from unconsolidated bitumen-bearing formations, comprising:
- (a) at least one nozzle, adapted to discharge a jet of hydraulic mining fluid through a liquid medium towards an erodable face of said formation, said jet being of sufficient velocity to separate eroding formation material into a bitumen-rich material and a sand-rich material;
 - (b) means adapted to move said nozzle towards said face as it erodes; and

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(c) recovery means adapted to recover said bitumen-rich material separately from said sand-rich material.

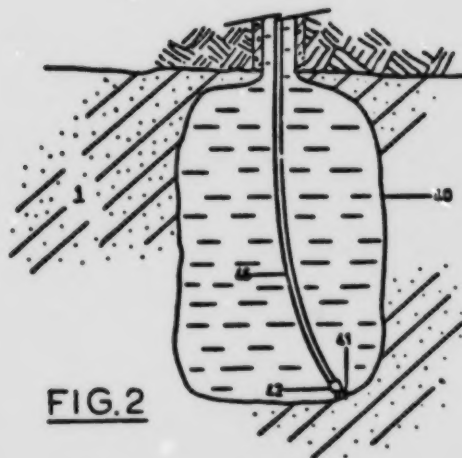
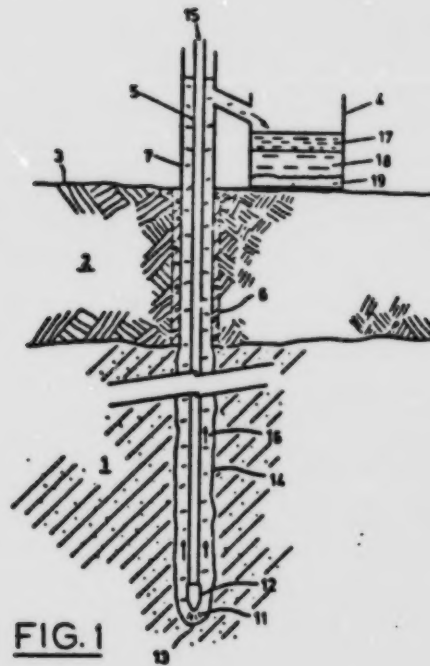
18. Apparatus as claimed in Claim 17, wherein said means to move said nozzle comprises tubing adapted to carry said hydraulic mining fluid.
19. Apparatus as claimed in Claim 17, wherein said means to move said nozzle permits said nozzle to sweep laterally as well as to move axially towards said eroding face.
20. Apparatus as claimed in Claims 18 or 19, wherein said means to move said nozzle comprises flexible tubing.
21. Apparatus as claimed in Claim 17, comprising a plurality of nozzles, said nozzles being rigidly mounted in a plane.
22. Apparatus as claimed in Claim 21, wherein said jets discharge substantially parallel to each other.

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PATENT AGENTS

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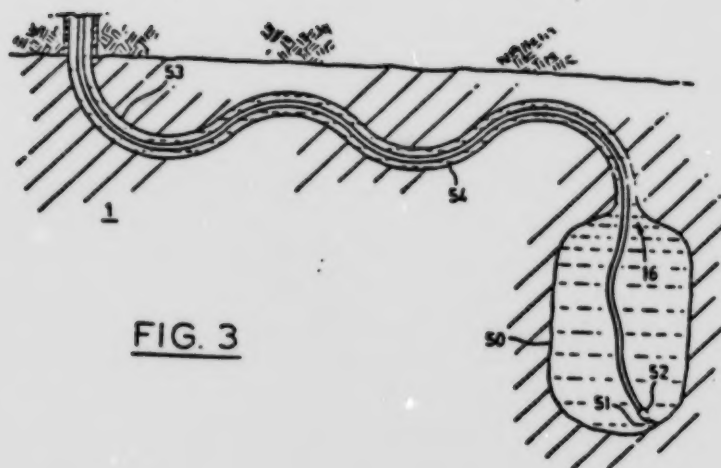
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FIG. 4

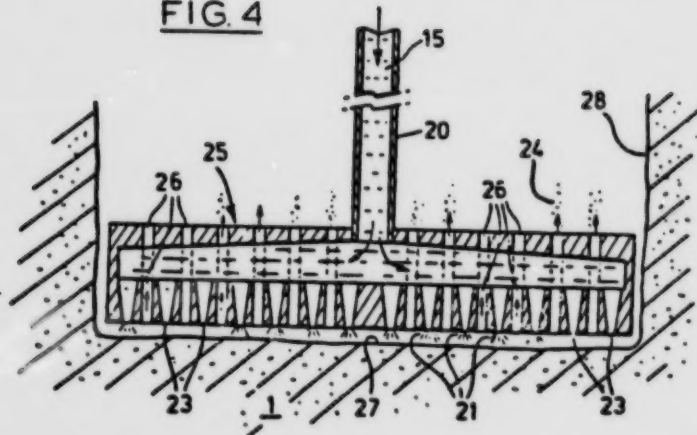
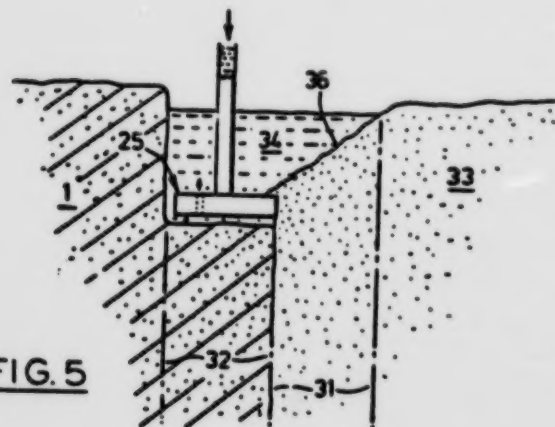


FIG. 5



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Alberta OIL SANDS

United States Patent [19]

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Heim et al.

[45] Jun. 26, 1984

[54] HEAVY OIL RECOVERING

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[21] Appl. No.: 294,629

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[51] Int. Cl.³ E21B 43/24

[52] U.S. Cl. 166/248; 166/252;

166/272

[58] Field of Search 166/50, 60, 245, 249,
166/248, 252, 272, 274, 263; 175/61

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[57] ABSTRACT

In a section of an oil field a first and only bore hole (5) is drilled through the strata (3) carrying heavy oil until the underlying stratum (4) void of heavy oil and enlarged to a cavern-like collection chamber (9). Around this first bore hole (5) a plurality of second bore holes (6) are drilled through the strata (3) carrying heavy oil to the stratum (4) in a pattern comprising several circles. A further pattern of third bore holes (7) is drilled also in a circle-like pattern through the strata (5) carrying heavy oil, which third bore holes (7) are followed by drainage channels (8), which extend to the collecting chamber (9). By means of electrodes arranged in the second bore holes (6) the heavy oil strata are preheated and thereafter steam is injected through the same bore holes (6) in order to drive flowable heavy oil against the third bore holes (7). A solvent is injected from the third bore holes (7) into the cone-like heavy oil accumulation (18) and by means of a further injection of steam from the second bore holes (6) the heavy oil rendered flowable by the solvent is driven toward the third bore holes (7) such to flow into the collecting chamber (9) out of which it is finally pumped to the first bore hole (6).

20 Claims, 10 Drawing Figures

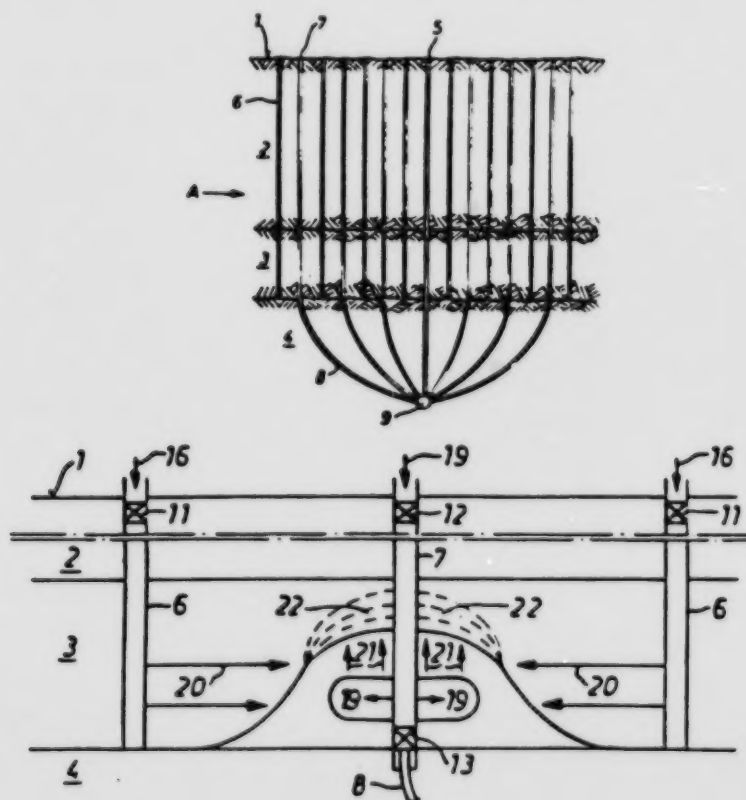


Fig. 1

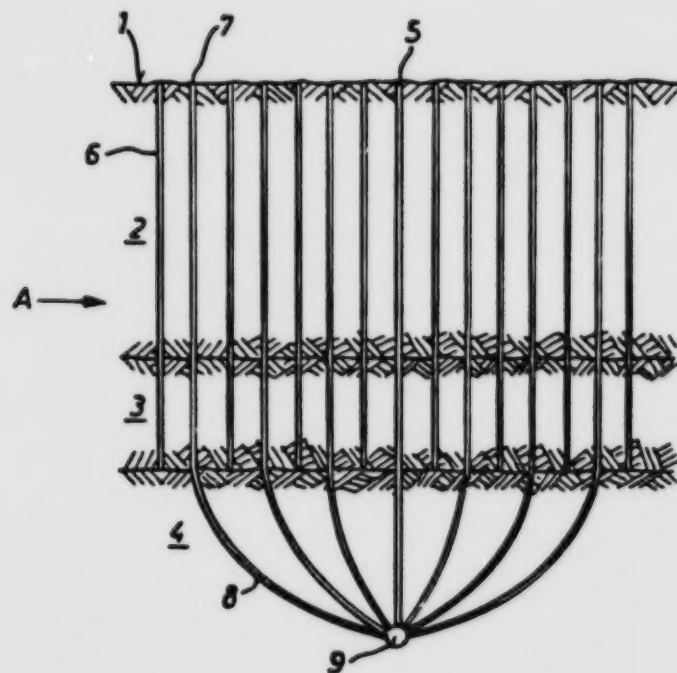


Fig. 2

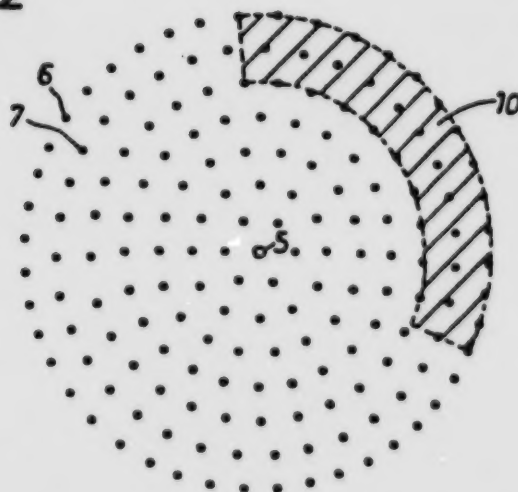


Fig. 3

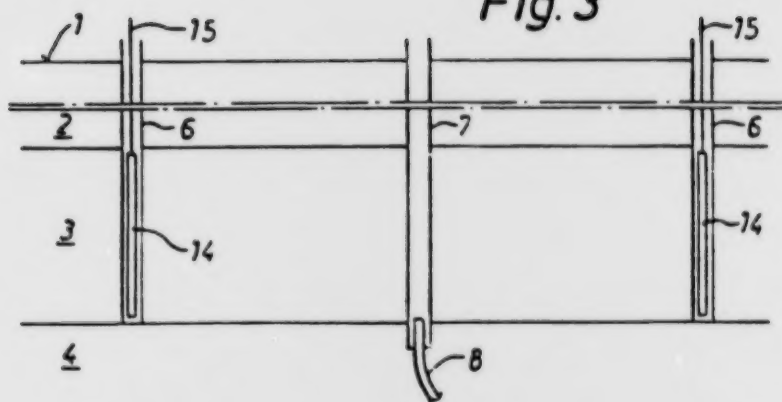


Fig. 4

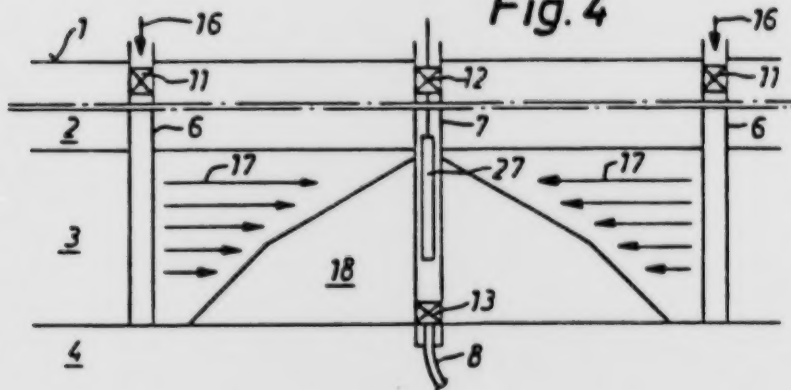
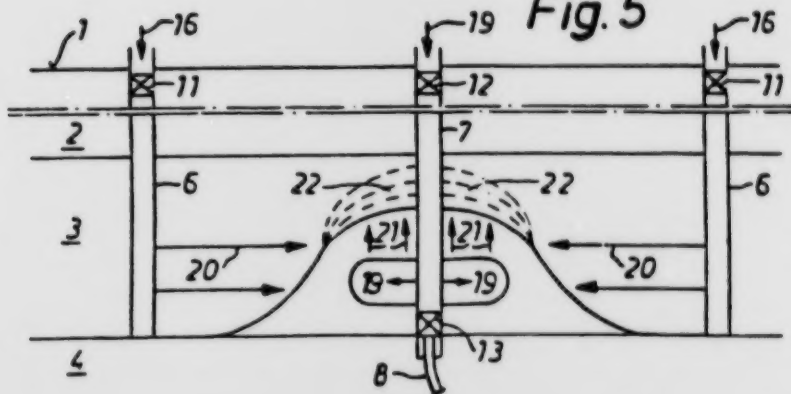


Fig. 5



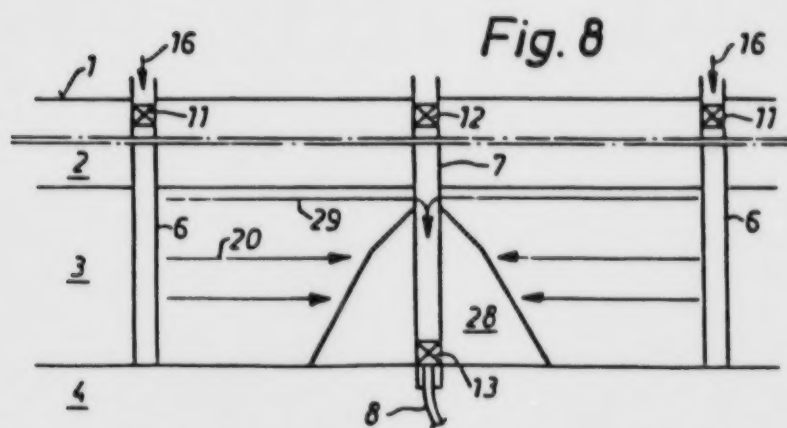
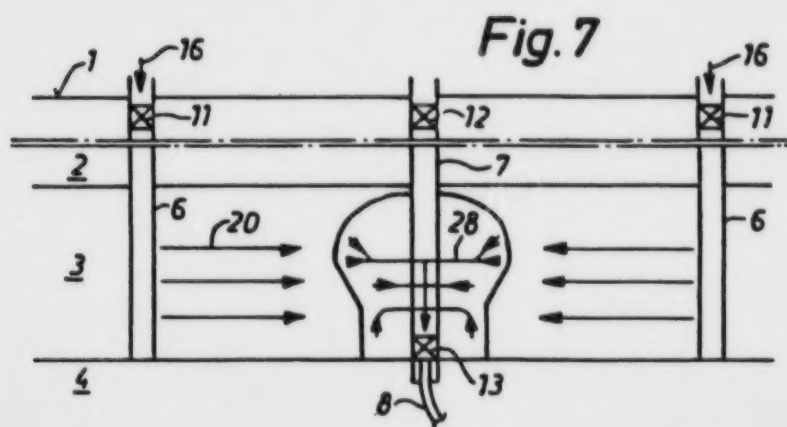
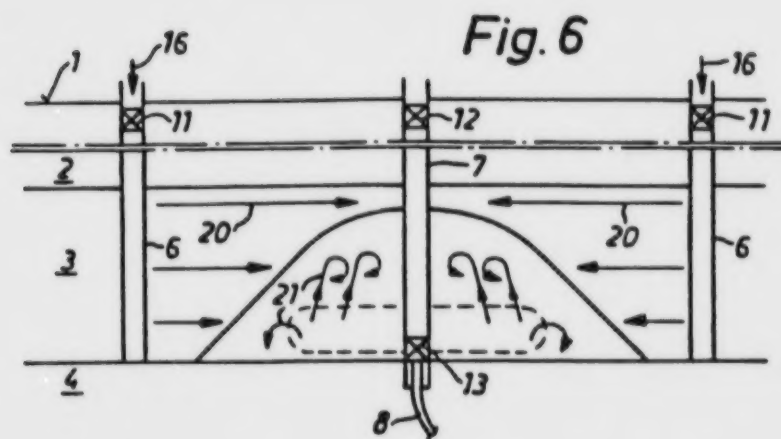
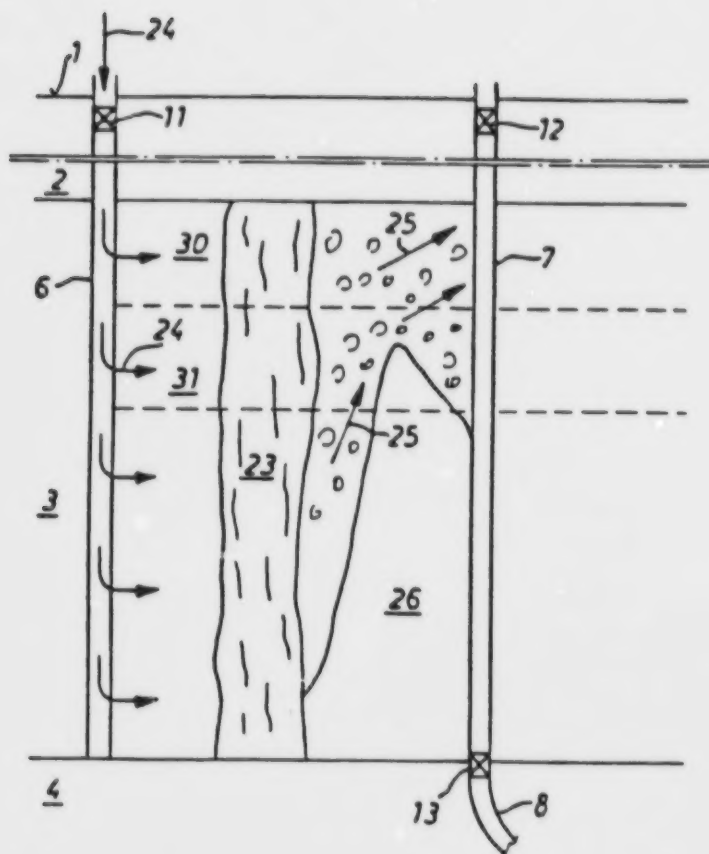


Fig. 9



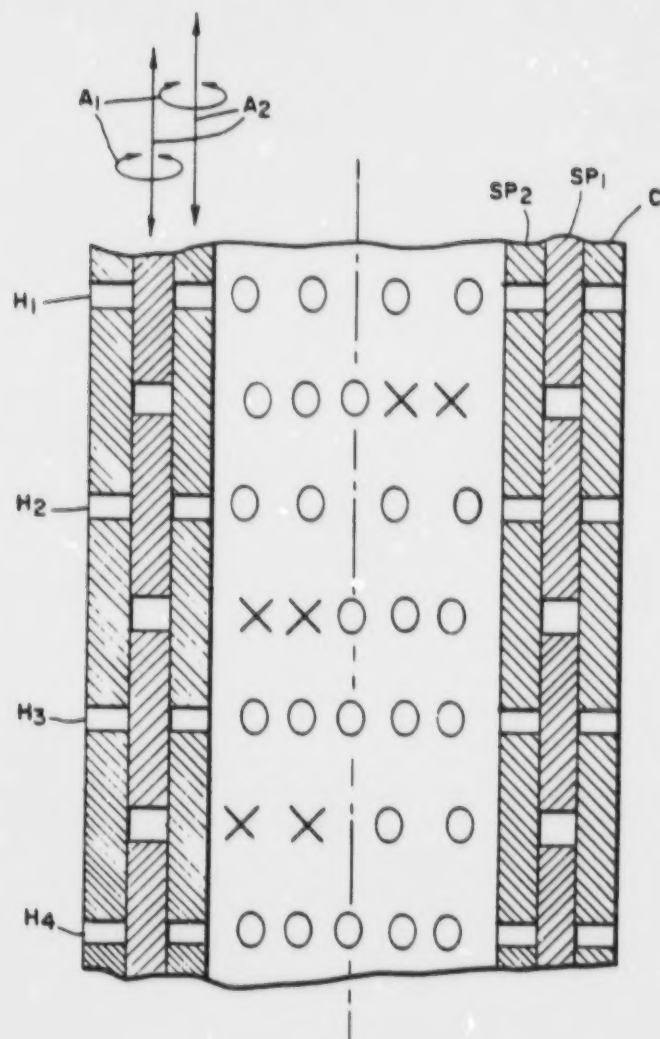


FIG. 10

HEAVY OIL RECOVERING

BACKGROUND OF THE INVENTION

The invention refers to a method of recovering heavy oil from a section of an oil field containing strata of oil shale or tar sand. Deposits of heavy oil which comprise oil shale from which kerogen can be recovered or oil sand from which bitumen can be recovered feature in common the drawback that no natural gas pressure is present, which drives the matter to be recovered toward the ground surface. Presently said deposits of heavy oil are mined by conventional mining methods and usually the heavy oil is recovered by means of a retorting method in plants located distant from said heavy oil deposits. This procedure is extremely costly, specifically because the mined crude rock must be transported from the respective heavy oil deposit to the processing plant and thereafter the depleted residues must be again transported back for a depositing thereof or must be transported to a different location.

Several methods by means of which the recovering of the heavy oil can be carried out directly at the location of the deposits have been proposed.

In U.S. Pat. No. 2,757,738 (Ritchey) sections of oil fields are heated by means of radio frequency waves to render the heavy oil flowable for the recovery thereof. However, this method has not succeeded in practice because the local heating in the area surrounding immediately the electrodes in order to generate the radio frequency waves has been to such a large extent that a coking of the crude oil occurred.

It is proposed in U.S. Pat. 3,538,488 to treat sections of oil fields by means of inserted steam to render the heavy oil flowable. However, this method is often impeded by the phenomenon that the steam following the path of the least resistance blows through from one bore hole to another bore hole such that only a limited section of the heavy oil containing strata is heated. Then, only a small percent of the heavy oil can be recovered because the sections of the strata containing heavy oil located at a distance from the channels flowed through by the steam are not heated and accordingly their heavy oil contents are not rendered flowable. This phenomenon of the blowing through of the steam is known in the art as "override" or "fingering".

U.S. Pat. No. 3,881,550 describes the utilization of solvents which can be manufactured at the oil field in an inexpensive way and by means of which the viscosity of the heavy oil may be lowered. According to the disclosure of this patent specification the solvents for the heavy oil are injected at a high temperature and consequently lie on top of the oil shale or tar sand strata and accordingly no complete mixing and dissolving of the heavy oil takes place.

The prior art also includes:

(a) above ground processing after mining tar sands or shale from depths of 200 to 1000 feet or for producing below ground retorts, e.g. by electropneumatic or electrolytic mining or fracturing as disclosed in U.S. Pat. Nos. 3,696,866 (Dryden/Bureau of Mines) granted Oct. 10, 1972, 3,103,975 (Hanson/Dow) granted Sept. 17, 1973, and 4,120,776 (Miller, Univ. of Utah) granted Oct. 17, 1978, tailored to Utah sands; see also 4,160,720;

(b) means for exploding shale or sands underground and drawing oil from resultant rubble chambers, e.g. as disclosed in U.S. Pat. Nos. 3,578,080 (Closmann/Shell Oil) granted May 11, 1971; 3,692,110 (Grady/Cities

Service) granted Sept. 19, 1972, 3,698,478 (Parker/Phillips Petroleum) granted Oct. 17, 1972, 4,061,196 (Bloomfield/NASA) granted Dec. 6, 1977 (laser retorting).

(c) propagation of pulsating energy waves for heating oil, e.g. as disclosed in U.S. Pat. No. 3,718,186 (Brandon) granted Feb. 27, 1973.

(d) variations of electro-conductive, inductive or rf heating as disclosed in U.S. Pat. No. 3,848,671 (Kern/Arco) granted Nov. 19, 1974 [see also Kern's 1975 U.S. Pat. Nos. 3,862,662, 3,874,450 and 3,920,072]; 3,948,319 (Pritchett/Arco) granted Apr. 6, 1976, 3,972,372, 3,989,107 and 4,008,761 and 2 Fisher) granted Aug. 3, 1976, and Feb. 22, 1977 [see also 4,049,053]; 4,010,796 (Kern/Petro-Canada, Imperial Oil, Cities Service) granted Mar. 8, 1977, Raytheon's U.S. Pat. Nos. 4,140,179 granted Feb. 20, 1979, 4,135,579 granted Jan. 23, 1979, and 4,193,451 and 4,196,329 granted Mar. 18 and Apr. 1, 1980.

(e) variations of pressures, steam or water injection cycles or production, injection well (and in some instances separate electrode well) spacings and arrangements, e.g. as disclosed in U.S. Pat. Nos. 4,084,637 (Todd/Petro Canada, Cities Service, Imperial Oil) granted Apr. 18, 1978, 3,946,809 (Hagedorn/Exxon) granted Mar. 30, 1976, 3,958,636 (Perkins/Arco) granted May 25, 1976, 4,133,382 (Cram/Texaco) granted Jan. 9, 1979.

(f) in situ gas generation, e.g. as in U.S. Pat. No. 4,037,655 and 4,199,025 (Carpenter/Electro Flood Co.) granted July 26, 1977, and Apr. 22, 1980.

(g) in situ combustion or dielectric heating, e.g. in U.S. Pat. No. 2,818,118 (Dixon/Phillips Petroleum) granted Dec. 31, 1957 [see also 2,889,882, 2,994,377] and 4,140,180 and 4,144,935 (Bridges/I.T.T.) granted Feb. 20 and Mar. 20, 1979.

(h) complex means for analysis of flooding progress as disclosed e.g. in U.S. Pat. No. 4,085,798 (Schweitzer et al./Schlumberger) granted Apr. 25, 1978, and references cited therein.

(i) variations of solvent treatment e.g. as in U.S. Pat. No. 4,141,415 (Wu/Texaco) granted Feb. 27, 1979.

(j) electrical heating as in U.S. Pat. Nos. 3,507,330, 3,547,193, 3,620,300, 3,605,888, 3,642,066 (Gill et al./T.E.C.).

The diversity and intensity of the underlying development efforts (and incidental patent activity illustrated above) show the high economic stakes and long felt needs (substantially unfulfilled or only partially fulfilled, as illustrated by cross-critiques in the introductions of the various patents above) for economic, effective and practical oil recovery processes usable in shale and/or tar sand regions.

It is a principal object of this invention to provide oil recovery method and apparatus fulfilling one or more of such needs.

It is a further particular object of this invention, consistent with the first stated object, to suppress overriding (aka channeling or fingering).

It is a further particular object of this invention, consistent with the first stated object, to avoid problems of well clogging.

It is a further particular object of this invention, consistent with the first stated object, to limit the need for expensive or complex equipment.

It is a further particular object of this invention, consistent with the first stated object, to limit the number of

maintenance cycles or the extent of interference with production occasioned by such cycles.

It is a further particular object of this invention, consistent with the first stated object, to more effectively utilize solvents in oil recovery and to lower critical specifications or cost of solvent usage.

It is a further particular object of this invention, consistent with the first stated object, to provide step by step working of an area for efficient usage of limited equipment resources.

It is a further particular object of this invention, consistent with the first stated object, to provide simple and economic means for process monitoring and control.

SUMMARY OF THE INVENTION

In accordance with the present invention, heavy oil is recovered from a section of an oil field containing strata of oil shale or tar sand by the method comprising the steps of drilling a first bore hole through said strata down into the underlying strata void of heavy oil, enlarging the end section of said first bore hole located in said underlying stratum to provide a collecting chamber, drilling adjacent to said first bore hole a plurality of second bore holes through said heavy oil containing strata in a pattern surrounding said first bore hole, drilling at locations between said second bore holes in the pattern surrounding said first bore hole a plurality of third bore holes through said heavy oil containing strata, each said third bore holes being followed by a drainage channel leading to said collecting chamber, preheating a section of said oil shale or tar sand strata located between said second and third bore holes by means of radio frequency waves or by an electrical resistance heating, applying a pressure with simultaneous exertion of further heat, said pressure being directed from said second bore holes to said third bore holes, whereby heavy oil rendered flowable thereby is transported towards the said third bore holes to flow therein through said drainage channels and into said collecting chamber to be extracted therefrom through said first bore hole, thereafter terminating said application of heat and pressure and subjecting said oil shale or tar sand strata repeatedly to a scavenging action to extract further heavy oil, filling the depleted section of said strata by a foamed material.

The applying of pressure with simultaneous exertion of heat can be carried out advantageously by steam injected into said second bore holes.

In accordance with a further advantageous embodiment of the method a vertically extending fire front is generated at said second bore holes, whereby the combustion gases stemming therefrom can generate the pressure with simultaneous exertion of heat.

Throughout the above mentioned variations of the invention temperature (or other parameters) can be measured at each of the third bore holes to detect the beginnings of channeling and in response thereto, the peripheral resistance of any such third bore hole can be varied by such measures as closing a spool valve therein. Channeling can also be restrained by varying the selection of "second" bore holes through which to generate driving pressures and/or by varying heating (or other) conditions. Such control can be implemented at specific levels of the second and third bore holes; shale formations substantially define segregated pay zones at different levels within an overall oil-containing zone, each pay zone being therefore, substantially separately controllable.

Solvent can be injected into the third bore holes to loosen up heavy oil driven into cone-like (apex up) formations around the third bore holes through one or more of the above described driving operations. The solvent can move from layer to layer within shale (although as noted above, heavy oil does not do so to any substantial degree). The solvent can optionally be any of a variety of inexpensive solvents (rather than the high grade, inexpensive solvents now used). The solvent mixes well with the oil and is therefore more effectively used than top layer applied solvents of the prior art. The solvent mixes well with the core oil formation and renders the oil more flowable, generally loosening and widening the core. Through renewed driving operations, conducted simultaneously with solvent injection or immediately thereafter, the oil is driven to and into the third bore holes. The additional collected oil is drained into the collecting chamber and pumped therefrom.

The above described filling of depleted areas by foam or other filler can then be conducted and electrodes, pumps, bore hole liners (if any) and spool valves can be withdrawn from the then worked out region for use in another region.

The invention can be practiced with heating of the oil at low enough levels to avoid coking. It comprises an effective approach to limit over-ride. The expense and environmental effects of above ground processing and underground explosion are avoided. Low energy requirements are involved herein compared to most state of the art methods. Inexpensive pumping equipment can be utilized for the collection chamber because direct pumping out of the narrow second or third bore holes is avoided. Clogging vulnerability of pumps is also reduced through the present invention.

Further objects, features and advantages of the invention will be apparent from the following description of preferred embodiments thereof taken in conjunction with the accompanying drawing, in which,

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 shows a vertically extending section through a section of an oil shale or tar sand,

FIG. 2 shows a plan view of the oil field shown in FIG. 1,

FIG. 3 shows on an enlarged scale the detail A of FIG. 1 whereby the electrodes for the resistance heating of the section are drawn,

FIG. 4 shows a section similar to the section of FIG. 3, whereby there is shown the injecting of steam,

FIG. 5 shows a section similar to the section of FIG. 3, whereby there is shown the injection of solvents,

FIG. 6 shows a section similar to the section of FIG. 3, whereby there is shown the mixing between the heavy oil and the solvents,

FIG. 7 shows a view similar to the view of FIG. 3, whereby the flowing off of the heavy oil which has been dissolved by the dissolving agents is shown,

FIG. 8 shows a view similar to the view of FIG. 3, whereby the repeated injection of steam is shown, and

FIG. 9 shows a view similar to the view of FIG. 3, whereby the use of a fire front is shown.

FIG. 10 shows a cross-section of a conventional spool valve construction usable to shut off flow in injection or production wells and to control directional characteristics of such wells.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Attention is now drawn to FIGS. 1 and 2. In FIG. 1 there is shown a vertical section through an oil field. The ground surface is designated by the reference numeral 1. Reference numeral 2 designates the so-called overburden comprising the strata containing no heavy oil which is located between the ground surface 1 and the strata 3 containing heavy oil. The thickness of this strata can amount to a few meters. Furthermore there is shown the stratum 4 void of heavy oil located under the strata 3 containing heavy oil.

In the chosen section of the oil field there is drilled firstly in its center a first bore hole 5, which hereafter is designated as collection hole 5. This collecting hole 5 is drilled in this embodiment of a high pressurized water drilling technique and extends through the overburden 2, through the section 3 of the strata carrying heavy oil down into the stratum 4 void of heavy oil. At the lower end of this collecting hole 5 a cavern-like collecting chamber 9 is formed again by means of the known high pressure water drilling method. The diameter of the first bore hole 5 is for instance 25 cm and the diameter of the collecting chamber 9 amounts to about 6 m. A not particularly shown pump is arranged in this collecting chamber 9 by means of which pump any material flowing into the collecting chamber 9 and being collected therein is extracted through the first bore hole 5.

A plurality of second bore holes 6 are drilled around the first bore hole 5 and through the strata 3 containing heavy oil and, in accordance with FIG. 2, in a pattern surrounding the first bore hole 5, which pattern in the present embodiment is described by concentric circles. These second bore holes 2 are identified hereinafter as injection holes 6. According to FIG. 1 these injection holes 6 extend merely until the lower limit of the strata 3 containing heavy oil and not into the stratum 4 void of heavy oil. The diameter of these injection holes 6 amounts for instance to 10 cm, may however be considerably smaller.

Thereafter third bore holes 7 are drilled through the strata 3 containing heavy oil. These are again arranged in a pattern surrounding the collecting hole 5, whereby every third bore hole 7 is located insofar between the injection holes 6, in that they are located also along concentric circular lines such as may be seen from FIG. 2. These third bore holes 7 are identified hereinafter as production holes 7. These production holes 7 are followed each by a drainage channel 8 which extends to the collecting chamber 9 of the first bore hole 5. In this context attention is drawn to FIG. 1, whereby it must be noted that the drawn course of this drainage channels is an example only, they may extend in a straight line and comprise a relatively abrupt transition to the respective production holes 7. The diameter of the production holes 7 is the same as in the case of the injection holes 6. The horizontal extent of this oil field containing this plurality of bore holes amounts for instance in every direction to about 125 m, which extent corresponds in FIG. 2 to the diameter of the outermost circular line which is defined by the injection holes 6 having the largest distance from the collecting hole 5. The distance between consecutive bore holes seen in radial direction of the oil field to be handled amounts in this embodiment to about 20 m.

Attention is now drawn to FIGS. 2 and 3. The method is now carried out in discrete annular sections

10 of the oil field such as shown in FIG. 2. Such an annular section is defined seen in a radial direction towards the outside and towards the inside each of a series of injection holes 6 which are located at two concentric sections of circular lines, whereby a series of production holes 7 are arranged therebetween and also along a section of a circular line. The oil field is now mined annular section by annular section, whereby it shall be noted already in this instance that each completely mined annular section 10 is filled by means of a foamed material.

In FIG. 3 the detail A of FIG. 1 is shown on an enlarged scale, whereby the section drawn extends along a radial line of the FIG. 5 through an annular section 10.

In FIG. 3 there is shown again the ground surface 1, the overburden 2, the section of the strata 3 containing heavy oil as well as the underlying stratum 4 void of heavy oil. Furthermore there are drawn two injection holes 6, between which there is located a production hole 7 including its drainage channel 8. In order to carry out the first step of the method electrodes 14 located in the injection holes 6 are used, which electrodes 14 are provided with feed lines 15. By means of these electrodes 14 the strata 3 containing heavy oil are heated by means of radio frequency waves or by means of an electrical resistance heating to carry out the preheating thereof. In order now to avoid a local overheating of the strata 3 containing heavy oil at locations immediately adjacent the injection holes 6 a cooling fluid is injected through these injection holes 6 during the preheating. Thereby a local coking of the heavy oil is avoided. By means of this preheating a part of the heavy oil may be rendered already flowable. This portion of the flowable heavy oil flows through the production hole 7 and down through the drainage channel 8 into the collecting chamber 9, out of which collecting chamber 9 such heavy oil is extracted by means of the not shown pump through the collecting hole 5.

The next following method step will now be explained by reference to FIG. 4. This FIG. 4 corresponds to a large extent to FIG. 3, whereby however closure- or valve members provided for the bore holes are shown schematically. Every injection hole 6 is provided with an injection valve 11, which is arranged at the upper end of each injection well 6. These valves 11 are not necessarily arranged below the ground surface 1 such as shown in the figure, they may be located above the ground surface 1 in a pipe stub connected to the injection hole 6. The same proves true also for the closure valve 12 of the production hole 7. A drainage valve 13 is located at the lower end of the production hole 7, by means of which the communication between the production hole 7 and its drainage channel 8 can be selectively interrupted or made, respectively.

After the preheating of the strata 3 carrying heavy oil by means of for instance radio frequency waves steam 16 is led to every injection hole 6. During the feeding of this steam the generation of radio frequency waves could be continued, which however is not absolutely necessary for carrying out the method. Out of the injection holes 6 the steam such as identified by the arrows 17 penetrates in the strata 3 carrying the heavy oil. It has now been mentioned previously that in accordance with methods of the prior art the injected steam 17 following the path of the least resistance flows relatively directly to the production hole 7, such that many portions of the strata 3 are bypassed such that they are not subjected to the pressure and the temperature of the

injected steam. In order to avoid this phenomenon, "override" or "fingering" specific measures are taken in accordance with the present method. A temperature feeler 27 is arranged in every production hole 7. As soon as a direct flowing of steam 17 from an injection hole 6 to a production hole 7 occurs, the sudden increase of temperature in the production hole 7 is detected by the temperature feeler 27. The injection of steam 17 from the injection holes 6, i.e. the location of the discharge out of the injection holes 6 as well as the direction of discharge of the steam 17 is controlled. If now a direct flowing through of steam from the injection holes 6 to the production holes 7 occurs which is detected by the temperature feeler 27, the discharge locations of the steam 17 out of the injection holes 6 into the strata 3 containing heavy oil located closest to the respective production hole 7 will be shut off. In this way it is possible to change by means of a suitable selection of the locations of the discharge of the steam from the injection holes 6 into the strata 3 containing heavy oil as well as the direction of flow of the steam flowing out of the injection holes 6. By means of this controlled injection of the steam 17 a breaking through of the steam the production holes 7 is eliminated, such that the respective section of the oil field is heated uniformly and at all locations. During the injection of the steam from the injection holes 6 the drainage valve 13 at the lower end of the production hole 7 is kept shut. The heavy oil rendered flowable collects now obviously around the production hole 7 specifically because heavy oil rendered flowable and contained in the upper strata 3 flows obviously due to gravity forces downwards such that a cone-like gathering 18 of flowable heavy oil collects around every production hole 7. It is not specifically to be noted, that steam is injected mainly at the lower strata of the injection holes 6 adjacent to the stratum 4 void of heavy oil such to keep specifically the lower section of the cone 18 of flowable heavy oil in a heated state.

Attention is now drawn to FIG. 5. From the lower section of the production hole 7 a heavy oil solvent, e.g. diesel oil is injected into the cone 18 of flowable heavy oil. Because the lower section of the cone 8 is held at a higher temperature as mentioned above the solvent can enter relatively easily out of the production hole 7 into the lower section of cone 18. It is now important to note that contrary to the prior art the injected solvent is cold and not heated. This solvent which is somewhat denser than the flowable heavy oil present in the cone 18 forms immediately after its injection out of the production hole 7 a pocket 19 at the base area of the cone 18. Further steam is injected from the injection holes 6 such as shown by means of the arrows 20, whereby contrary to the injected steam 17 of FIG. 4 the latter injected steam injected during the injection of the solvent acts only against a lower section of cone 18. Accordingly the heavy oil and the solvent located in the lower portion of the cone 18 are heated and rise in the direction of the arrows 21 towards the apex of the cone whereby a widening of the apex of the cone takes place such as is indicated in FIG. 5 by means of the reference numerals 22.

Attention is now drawn to FIG. 6. The drainage valve 13 of the production hole 7 still being kept shut and during a continuing injection of steam the solvents mix thoroughly with the heavy oil of the cone, such as is shown by means of the arrows 21, such that a as large as possible intermixing is achieved. Thereby the viscos-

ity of the heavy oil portions is lowered by a factor of 99% or more. In order to promote the mixing and heating further steam to enter is brought to act onto the complete height of the cone as is shown in FIG. 6.

The next following step is shown in FIG. 7. The steam 20 injected from the injection holes 6 is brought to act merely again against the lower section of the previous cone 18 containing dissolved heavy oil. The purpose of this is to let the upper portion of the strata containing heavy oil to cool off such that a sealing off against a not wanted flowing out of steam (override) is achieved. However, the lower part of the strata of the cone 18 are heated further by means of injected steam 20. Due to the increased temperature together with the results of the injection of the solvent an easily flowable mixture has been formed. Now the lower drainage valve 13 of the production hole 7 is opened whilst maintaining the closure valve 12 closed, to make connection between the production hole 7 and the drainage channel 8 such that the mixture flows into the production hole 7 through the drainage channel 8 and down into the collecting chamber 9, from which collecting chamber 9 it will be pumped out via the collecting hole 5.

In this way one operating cycle for the recovery of heavy oil is basically completed. Attention is now drawn to FIG. 8. Again the strata 3 carrying heavy oil are subjected to a pressure by the agency of injected steam 16 led into the injection holes 6. Thereby firstly a flowing through of steam from the injection holes 6 to the production hole 7 will take place and accordingly the exit of steam out of the injection holes 6 is closed off at locations adjacent to the underlying stratum 4 void of heavy oil. However, an entering of steam into the middle section of the strata 3 is allowed such as is shown with arrows 20. Accordingly, after a certain time span a flowing through of steam from the injection holes 6 to the production hole 7 occurs in the upper region of the strata 3 carrying heavy oil such as is shown by the arrow 29. After this has occurred, the injection of steam out of the injection holes 6 in mentioned upper area is terminated and further steam is injected only in the area identified by the arrows 20. Accordingly, a new, smaller cone 28 of heavy oil (including dissolved portions because obviously also a part of the solvent remains in the strata) is formed and the previously mentioned method steps are carried out once more. This whole procedure will be repeated several times until the complete annular section (see FIG. 2) contains no heavy oil. Thereupon a foamed material is injected in through the bore holes into the strata 3 having previously carried heavy oil. The reason thereto is to seal the mined portion against a flowing through of steam, heavy oil, etc. in a wrong, unwanted direction. Accordingly, one section after the other of the oil field is mined, whereby the entire work begins at the radially outermost ring of the section of the oil field in question and proceeds towards the collecting hole 5.

In FIG. 9 there is shown a further embodiment whereby steam is not utilized. Here the method involving utilization of a fire front is carried out. A vertically extending fire front 23 is generated at the injection holes 6 in accordance with a known procedure. Thereby combustion gases 25 are generated, such that again pressure and temperature are exerted onto the heavy oil portions to be recovered, whereby again a cone 26 of flowable heavy oil is formed. The direction of the spreading of the fire front 23 is again controlled by means of fresh air 24, the locations of the entry of the

fresh air out of the injection hole 6 into the strata 3 containing heavy oil as well as the direction of entry thereof is controlled selectively whereby again temperature feelers are utilized which are arranged in the production holes 7 (not shown in FIG. 9). Should a local blocking of the spreading of the fire front 23 occur, the area in question will be brought to a higher temperature by means of the previously mentioned radio frequency waves heating such to insure the spreading of the fire front 23. After the termination of the fire front 23 hot pressurized water will be injected through the injection holes 6 into the strata 3 carrying heavy oil. Thereby the closure valve 12 at the upper end of every production hole 7 as well as the corresponding drainage valve 13 is shut off. After the strata 3 carrying heavy oil are saturated by pressurized water, the injection valve 12 of every injection hole 6 is shut off, whereby the hot pressurized water is heated further by means of the heat generated by the fire front in the strata 3. It is important thereby that the temperature of the injected water is higher than about 105° C., whereby should this be necessary, a further heating by means of radio frequency waves is carried out to achieve this situation.

Thereafter the closure valve 12 and the drainage valve 13 of every production hole 7 are opened simultaneously, whereby simultaneously a communication between the injection holes 6 and a portion of the strata 3 carrying heavy oil is formed, which portion of the strata is identified in FIG. 9 by means of the reference numeral 30. Thereby a sudden pressure relief and obviously sudden flashing of the water into steam in this portion of the strata 30 occurs. In this way heavy oil is liberated and is driven against the respective production hole 7 through which it flows down through the drainage channel 8 into the collecting chamber 9. Thereafter the section 30 is filled with a foamed material and a sudden flashing into steam is carried out in the subsequent strata portion 31 located immediately below. This method is carried out step by step in a downwards direction against the stratum 4 void of heavy oil until the complete heavy oil content is driven out.

Also this method is carried out section 10 by section 10 such to recover completely the heavy oil thereof.

FIG. 10 shows a spool valve construction usable in wells 6 and 7 to provide peripheral horizontal directional and vertical control as described above. The valve comprises a casing C and spools SP1 and SP2, both movable in directions indicated by arrows A1 and A2. The casing C has holes H1-H4. The spools have staggered holes which allow flow through all radial directions, all heights or for various permutations of cut off of some radial directions and/or some height locations of holes, as described above for system operation.

It is evident that those skilled in the art, once given the benefit of the foregoing disclosure, may now make numerous other uses and modifications of, and departures from the specific embodiments described herein without departing from the inventive concepts. Consequently, the invention is to be construed as embracing each and every novel feature and novel combination of features in, or possessed by, the apparatus and techniques herein disclosed and limited solely by the scope and spirit of the appended claims.

What is claimed is:

1. A method of recovering heavy oil from a section of an oil-field containing oil bearing strata, comprising the steps of:

drilling a first bore hole (5) through said heavy oil containing strata (3) down into the underlying stratum (4) void of heavy oil.

enlarging the end section of said first bore hole (5) located in said underlying stratum (4) such to provide a collecting chamber (9),

drilling adjacent of said first bore hole (5) a plurality of second bore holes (6) through said heavy oil containing strata (3) in a pattern surrounding said first bore hole (6),

drilling at locations between said second bore holes (6) in a pattern surrounding said first bore hole (5) a plurality of third bore holes (7) through said heavy oil containing strata (3), each said third bore holes (7) being followed by a drainage channel (8) leading to said collecting chamber (9),

preheating a section of said heavy oil containing strata (3) located between said second (6) and said third bore holes (7),

applying a pressure with simultaneous exertion of further heat, said pressure being directed from said second bore holes (6) to said third bore holes (7), whereby heavy oil rendered flowable thereby is transported towards said third bore holes (7) to flow therein through said drainage channels (8) and into said collection chamber (9) such to be extracted therefrom through said first bore hole (5), thereafter terminating said application of heat and pressure and subjecting said oil shale and tar sand strata (3) repeatedly to a scavenging action such to extract further heavy oil,

filling the depleted section of said strata (3) by a foamed material.

2. The method of claim 1, wherein said preheating is carried out by an application of radio frequency waves generated by a radio frequency wave generating means (14) arranged in each said second bore holes (6), and wherein a cooling fluid is applied to the section of said strata (3) adjacent to and surrounding said radio frequency wave generating means to avoid a local overheating and consequent coking of heavy oil.

3. The method of claim 1, wherein the distribution of pressure within said strata (3) is monitored continuously, and wherein the locations of attack and the directions of force of said pressure are adjusted in accordance with the measured data.

4. The method of claim 3, wherein said monitoring of said distribution of the pressure within said strata (3) is carried out by measuring the temperature in each said third bore holes (7).

5. The method of claim 1, wherein said applying of pressure with simultaneous exertion of heat is generated by means of steam fed into said second bore holes (6).

6. The method of claim 1, comprising an injection of a heavy oil solvent from said third bore holes (7) at a location adjacent to said underlying stratum (4) void of heavy oil.

7. The method of claim 6, wherein said injection of said solvent is periodically interrupted by a further injection of steam from said second bore holes (6) such to drive further flowable heavy oil towards said third bore holes (7).

8. The method of claim 1, wherein a vertically extending fire front (23) is generated at said second bore holes (6), wherein the combustion gases (25) stemming therefrom generate said pressure with simultaneous exertion of heat

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9. The method of claim 8, wherein the distribution of said pressure and temperature generated by said gases (25) is controlled by a selective injection of combustion air (24) from said second bore holes (6).

10. The method of claim 8, wherein a local blocking of the spreading of said fire front (23) is overcome by a further application of heating by radio frequency waves.

11. The method of claim 9, wherein upon termination of said fire front (23) pressurized hot water is injected into said strata (3) at locations along the complete longitudinal extent of said second bore holes (6), said water being heated further by the heat generated by said fire front (23), whereby said second (6) and third bore holes (7) are shut off at the ground surface (1) and said third bore holes (7) are kept separated from their drainage channels (8).

12. The method of claim 11, wherein the temperature of said injected water is kept above a value of 105° C. by a further heating by means of radio frequency waves, and wherein all bore holes are kept in a shut off condition.

13. The method of claim 12, wherein said second (6) and said third bore holes (7) are brought into communication with the uppermost strata (3), and wherein simultaneously said third bore holes (7) are opened at ground surface (1) and are brought into communication with their drainage channels (8), whereby said second bore holes (6) are kept shut off at the ground surface (1) such that the pressure existing in said uppermost strata is relieved and a sudden flashing of said superheated water into steam is generated such that further heavy oil is liberated and driven against said third bore holes (4) such to flow into said collecting chamber (9), and wherein said strata depleted of heavy oil are filled by a foamed material.

14. The method of claim 13, wherein said pressure relieving, said sudden flashing into steam and said insertion of foamed material are carried through in several consecutive cycles, and wherein every cycle is executed at a consecutive adjacent location along said bore holes and thus in consecutively different strata containing heavy oil, proceeding from the uppermost strata carrying heavy oil and ending by the lowermost strata carry-

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ing heavy oil located adjacent said underlying stratum (4) free of heavy oil.

15. The method of claim 1, wherein during the application of pressure and simultaneous exertion of heat said third bore holes (7) are kept in communication with their drainage channels (8) and steam (17) is injected from said second bore holes (6) into the strata (3) containing heavy oil, followed by a closing off of said third bore holes (7) from said drainage channels (8) and an insertion of a heavy oil dissolving agent (19) from said third bore holes (7) at a location of said heavy oil containing strata (3) at a location adjacent said underlying stratum free of heavy oil (4), whereupon at a corresponding level further steam (20) is inserted from said second bore holes (6).

16. The method of claim 15, wherein said insertion of steam (17), said insertion of a dissolving agent (19) and said insertion of further steam (20) are carried out repeatedly until said heavy oil containing strata (3) are depleted of heavy oil.

17. The method of claim 15, wherein said depleted sections (3) are filled by a foamed material and the method of recovering heavy oil is continued at an adjoining section of said oil field.

18. Method of recovering underground oil in a selected region comprising the steps of forming a production well in such region, surrounded by injection wells, heating the oil, injecting pressurized fluid through said injection wells to drive oil in the region into a conical formation around the production well while closing off the production well to escape of oil, injecting cold solvent via the production well into a lower section of the conical formation and maintaining the formation intact to prevent escape of heat and allow thorough mixing of the solvent with the oil, heating the oil/solvent mixture and opening the production well and terminating solvent injection to allow escape of oil/solvent mixture through the production well.

19. Method of claim 18 carried out repetitively in said selected region.

20. Method of claims 18 or 19 followed by the step of backfilling the selected region with solid material after oil removal therefrom.

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(19) (CA) **CANADIAN PATENT** (12)

(54) METHOD OF RECOVERING VISCOUS PETROLEUM EMPLOYING
HEATED SUBSURFACE PERFORATED CASING CONTAINING A
MOVABLE DIVERTER

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No. OF CLAIMS 9

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01 METHOD OF RECOVERING VISCOUS PETROLEUM
 EMPLOYING HEATED SUBSURFACE PERFORATED CASING
 CONTAINING A MOVABLE DIVERTER

05 BACKGROUND OF THE INVENTION

05 This invention relates to recovering viscous
 petroleum from petroleum-containing formations. Through-
 out the world there are several major deposits of high-
 viscosity crude petroleum in oil sands not recoverable in
10 their natural state through a well by ordinary production
 methods. In the United States, the major concentration of
 such deposits is in Utah and California. By far the larg-
 est deposits in the world are in the Province of Alberta,
 Canada. The depths of these deposits range from surface
15 outcroppings to about 2000 feet.

15 To date, none of these deposits has been pro-
 duced commercially by an in-situ technology. Two commer-
 cial mining operations exist, and they are in a shallow
 Athabasca deposit and others are proposed. There have
20 been many in-situ well-to-well pilots, all of which used
 some form of thermal recovery after establishing communi-
 cation between an injector well and a producer well.
 Normally such communication has been established by intro-
 ducing a pancake fracture. The displacing or drive mecha-
25 nism has been steam and combustion or steam and chemicals.
 Another proposal is to develop well-to-well communication
 by injecting steam over a period of several years into a
 high water saturation zone underlying the tar sand deposit
 at a depth of around 1800 feet. Probably the most active
30 in-situ pilot in the oil sands uses the huff-and-puff
 single-well method of steam stimulation. This pilot has
 been producing about 5000 barrels of viscous petroleum per
 day for several years from about 50 wells.

35 The most difficult problem in any in-situ well-
 to-well viscous petroleum project is establishing and



01 maintaining communication between injector and producer.
In shallow deposits, fracturing to the surface has
occurred in a number of pilots whereupon satisfactory
drive pressure could not be maintained. In many cases,
05 problems arise from healing of the fracture when the vis-
cous petroleum that had been mobilized through heat cooled
as it moved toward the producer. The cool petroleum is
essentially immobile, since its viscosity in the Athabasca
deposits, for example, is on the order of 100,000 to
10 1,000,000 cp at reservoir temperature.

As noted, the major problem of the economic
recovery from many formations has been establishing and
maintaining communication between an injection position
and a recovery position in the viscous oil-containing
15 formation. This is primarily due to the character of the
formations, where effective mobility of fluids may be
extremely low, and in some cases, such as the Athabasca
Tar Sands, virtually nil. Thus, the Athabasca Tar Sands,
for example, are strip mined where the overburden is
20 limited. In some tar sands, hydraulic fracturing has
been used to establish communication between injectors and
producers. This has not met with uniform success. A
particularly difficult situation develops in the inter-
mediate overburden depths, which cannot stand fracturing
25 pressure.

Heretofore, many processes have been utilized in
attempting to recover viscous petroleum from viscous oil
formations of the Athabasca Tar Sands type. The applica-
tion of heat to such viscous petroleum formations by steam
30 or underground combustion has been attempted. The use of
vertical slotted liners positioned in the viscous oil
formation as a conduit for hot fluids has also been sug-
gested. However, these methods have not been overly suc-
cessful because of the difficulty of establishing and
35 maintaining communication between the injector and the

producer. Clearly, if one could establish and maintain communication between injector and producer, regardless of the drive fluid or recovery technique employed, it would open up many of these viscous petroleum deposits to a number of potentially successful projects.

BRIEF DESCRIPTION OF THE INVENTION

The present invention provides a method of assisting the recovery of viscous petroleum from a petroleum-containing formation comprising: (a) forming a generally horizontal hole through a petroleum-containing formation; (b) inserting a solid-wall, hollow tubular member into said generally horizontal hole to provide a continuous flow path through said formation; (c) perforating said tubular member; (d) flowing a hot fluid through the interior of said tubular member to heat viscous petroleum in said formation outside said tubular member to reduce the viscosity of at least a portion of the petroleum adjacent the outside of said tubular member to provide a potential passage for fluid flow through said formation adjacent the outside of said tubular member; (e) positioning a movable diverter within said tubular member; (f) injecting a drive fluid into said formation through said perforations and into said passage adjacent the outside of said tubular member to promote movement of the petroleum through said passage adjacent the outside of said tubular member to a recovery position for recovery from said formation; (g) monitoring the production of petroleum and drive fluid at said recovery position; (h) and positioning said diverter within said tubular member to selectively control the injection of drive fluid through said perforations to maintain said passage adjacent the outside of said tubular member and promote movement of said petroleum.

The tubular member may initially be perforated in the zone where recovery of the viscous petroleum is desired or the

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tubular member may be subsequently perforated to provide passage ways into the formation for the hot fluid passing within the tubular member. An initial breakthrough between the formation and the producer well establishes flow of the heated viscous petroleum and the hot fluid into the producer well. The diverter, for example, a settable, inflatable packer, is placed within the tubular member to cause the hot fluid to pass out through the perforations into the formation--there acting as a drive fluid to force the heated petroleum toward the producer well. In most cases the initial placement of the packer will be close to the producing well in order to maximize

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01 the pressure gradient between drive fluid and producing
well, thereby facilitating early communication and petrol-
eum production. The ratio of produced petroleum to drive
fluid is monitored in the producer well to recognize an
05 indication of excessive pass-through of the drive fluid
and, based on the observed ratio, the diverter is moved
within the tubular member to optimize the petroleum eco-
nomic production rate and minimize the drive fluid pass-
through.

10 The diverter may be moved back and forth within
the casing between the end near the production well and
the end near the injection well to maximize both the heat-
ing of the formation and the movement of the heated vis-
cous petroleum into the producer well. In the event of an
15 unwanted breakthrough of the drive fluid the diverter can
be moved to another location within the casing so as to
maintain a desired formation heating and petroleum move-
ment as the breakthrough heals.

In the preferred form, the hot fluid which is
20 flowed through the tubular member is steam, and the drive
fluid used to promote movement of the petroleum is also
steam. Under other conditions, the hot fluid and the
drive fluid may be injected intermittently. The
injectivity of the drive fluid into the formation is con-
25 trolled to some extent by adjusting the condition of the
hot fluid flowing through the tubular member. In this
manner, the sweep efficiency of the drive fluid in the
formation may be improved.

In one form, the present invention deals with
30 the recovery of viscous petroleum from a tar sand forma-
tion of an Athabasca type. An injection shaft and a
recovery shaft are formed and extend from the earth's sur-
face through the tar sand formation. A hole is formed
through the tar sand formation between the injection shaft
35 and the recovery shaft, and a solid-wall, hollow tubular

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10 member is inserted into the hole to provide a flow path from the injection shaft to the recovery shaft through the tar sand formation. A hot fluid, preferably steam, is flowed through the interior of the tubular member to heat the viscous petroleum in the tar sand formation between the injection shaft and the recovery shaft outside the tubular member thus reducing the viscosity of at least a portion of the viscous petroleum adjacent the outside of the tubular member to provide a potential passage for fluid flow through the tar sand formation adjacent the outside of the tubular member. A drive fluid is injected into the formation through perforations in the tubular member to promote flow of petroleum toward the recovery shaft and the petroleum is recovered from the recovery shaft. As noted, the preferred hot fluid is steam, although other fluids may be used. Steam also is preferred for use as a drive fluid. In some situations, other fluids such as gas, water or solvents may be useful drive fluids, either alone or in combination with steam.

Advantages of the present invention will become apparent when the description is

01 read in view of the accompanying drawings which are made a
part of this specification.

BRIEF DESCRIPTION OF THE DRAWINGS

05 FIG. 1 is an elevation view partially in section
illustrating one form of apparatus assembled in accordance
with the present invention for use in recovering viscous
petroleum from an underground formation.

10 FIG. 2 is a sectional view representing a prior
art method of recovering viscous petroleum from an under-
ground formation.

FIG. 3 is a sectional view representing an in-
jection profile expected with the initial position of a
diverter in accordance with the method of the present
invention.

15 FIG. 4 is a sectional view representing an in-
jection profile expected with a subsequent position of a
diverter in accordance with the method of the present
invention.

DETAILED DESCRIPTION OF THE
EMBODIMENTS OF THE INVENTION

20 Referring now to the drawings, and to FIG. 1 in
particular, where the preferred embodiment of apparatus
assembled in accordance with the invention is illustrated,
FIG. 1 shows a pair of spaced-apart wells or shafts, indi-
cated generally by the numerals 10 and 12, which penetrate
25 the earth to a viscous petroleum or tar sand formation
14. For ease in description, well 10 will be termed an
injector shaft 10 and well 12 will be termed a producer
shaft 12. As here illustrated, injector shaft 10 may be a
continuous well connecting with producer shaft 12 at 13.
30 A solid-wall, hollow tubular member or casing 16 is in-
serted through at least the generally horizontal
portion 18 of the well 10. The tubular member 16 is pre-
ferably steel and may be made up of one piece or many
35 connecting joints as a tubing string. The outside of the

01 tubular member 16 contacts the tar sand formation 14 in
the horizontal portion 18 and eventually enters the pro-
ducer shaft 12. The producer well 12 is provided with a
casing 22 with perforations at 23, and enclosed therein in
05 a producing string 24 for carrying liquids to the surface
above the subsurface formation.

It is not necessary that the injector well
connect with the producer well, it is only necessary that
the injector be in the near vicinity of the producer well.
10 Near vicinity can mean as far as about ten feet from the
producer well. The end of the horizontal portion 18 of
the producer should be close enough to accomplish the
development of a communication path for heated viscous
petroleum from the formation into the producer well 12
15 through perforations 23 in casing 22.

The generally horizontal portion 18 may vary
many degrees from horizontal. It is desirable to have the
casing in an alignment that will maximize the heating and
driving effect of fluids passing through the casing and
20 for that reason the casing should be generally horizontal.

The injector well 10 is provided with a well
head 26 at the earth's surface including a packing
gland 28 through which a hollow member 30 passes for entry
into the well. Within the well 10 at the horizontal por-
25 tion 18, a diverter, here shown as an inflatable
packer 32, is secured between shoulders 34 and 36. At the
surface, the hollow member passes over a pulley 38 and
onto a reel 40 on hoist mechanism 42. Spacing means 43
are provided as needed to align the hollow member 30 with-
30 in the casing 16. A packer inflation and position control
44 provides control for the positioning of the packer 32
within the tubular member 18 and provides surface control
for the inflation and deflation of the packer.

01 The well head 26 also provides an entry path for
a drive fluid into the well 10 from drive fluid source 46
through valve 48.

05 The horizontal portion 18 of the hollow tubular
member 16 may be initially perforated at 50 or may be per-
forated after being positioned in the subsurface formation
and after functioning as a hollow passage way between the
injector well 10 and the producer well 12.

10 The surface end of the producer well 12 is pro-
vided with a well head at 52 through which a pump mecha-
nism 54 may operate to lift liquids from the subsurface to
the surface. The lifted liquids pass into a monitor
mechanism 56 where the ratio of produced petroleum to
produced drive fluid is determined. The monitor 56
15 includes means for controlling the packer inflation and
position control 44 and the drive fluid source 46 to
accomplish a desired positioning of the packer 32 within
the member 18 and a desired temperature and pressure of
the drive fluid. The mechanism by which these desired
20 controls is accomplished is not essential to the present
invention.

 FIG. 2 illustrates a prior art form of producing
viscous petroleum employing an injector well to producer
well connection scheme. As here illustrated, a cased
25 injection well 60 penetrates vertically through an earth
formation of a viscous petroleum or tar sand formation
62. A cased production well 64 is positioned generally
parallel to and spaced from the injection well 60. A
tubular member 66 is passed down through the interior of
30 the injection well 60, out through the casing into the
formation 62, then through the formation 62 to the cased
production well 64, through the casing of the production
well 64 and up to the earth's surface through the interior
of the production well. As shown in FIG. 2 the horizontal
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01 portion 68 of the tubular member is ideally shown as hori-
zontal through the formation 62 and in contact with the
formation at its exterior. The injection well and produc-
05 tion well are perforated at 70 while the tubular member 66
has a solid exterior along its length.

Steam, or another hot fluid, is pumped through
the tubular member 66 to heat the formation surrounding
the horizontal portion 68.

10 Another hot fluid, or steam, is pumped through
injection well 60, out through perforations 70 and into
the formation 62 to function as a drive fluid for moving
heated viscous petroleum through the formation 62 into the
production well 64 at perforations 70 therein. Lines 72
and 74 are illustrative of isothermal profiles that might
15 be produced as the drive fluid is pumped into the forma-
tion heated by the hot fluid passing through the horizon-
tal portion 68 of tubular member 66.

A problem occurs with the prior art scheme when
the drive fluid finds a relatively low resistance path
20 through the formation from the injection well to the pro-
duction well or out into a permeable path through the
formation. Such a condition can exist when the viscous
petroleum immediately adjacent to the tubular member 68
becomes mobile enough to be pushed into the production
25 well or pushed at least laterally far enough away from the
tubular member 68 to establish a finger breakthrough for
the drive fluid. Once that condition has occurred, it is
difficult to reestablish a continuously moving heated
viscous petroleum to maintain the desired production.

30 The prior art scheme also has a problem of main-
taining an established flow path for the drive fluid
through the formation heated by the fluid in the tubular
member. It is possible that the drive fluid may find a
low resistance path into or through the formation in a
35

01 path that does not move the heated viscous petroleum to-
ward the production well. With only a single source for
the drive fluid there is little likelihood that the loss
of drive fluid into the formation can be controlled.

05 FIG. 3 and FIG. 4 illustrate the scheme of the
present invention with apparatus positioned in a subsur-
face viscous petroleum or tar sand formation 14. These
figures illustrate only the horizontal portion 18 of the
tubular member 16 and the packer 32 in its placement and
inflation position within the hollow member 30 as shown in
10 FIG. 1. FIG. 3 illustrates the packer 32 adjacent to the
casing 22 of production well 12 at perforations 23.
FIG. 4 illustrates the packer positioned laterally along
and adjacent to other perforations 50 in the tubular mem-
15 ber 18.

FIG. 3 and FIG. 4 illustrate idealized paths for
injected hot fluids through the perforations 50 in the
tubular member 18, into the formation 14 and along the
exterior of the tubular member 18 into the production well
20 12 through perforations 23 in the casing 22. Initially
the tubular member 18 may be a conduit for hot fluids
between the injection well 10 and the production well 12
to heat the viscous petroleum adjacent to the exterior of
the tubular member and radially out into the formation.
25 When the formation has been sufficiently heated to make
the viscous petroleum mobile, the packer 32 may be placed
in the tubular member 18 to deflect the hot fluid out into
the formation to function as a pusher fluid to move the
viscous crude into the production well through perfora-
30 tions 23 in the casing 22. The tubular member 18 may have
been installed with perforations 50 or the perforations
may be added after the formation has been heated. In
either case, the hot fluid now passes out into the forma-
tion through perforations 50 to move the heated viscous
35 petroleum along the formation.

01 As shown in FIG. 1, the produced fluids are
brought to the earth's surface by use of a pump 54 or
other conventional means, where the fluid is monitored for
content of petroleum and pusher fluid. When the ratio of
05 these two fluids indicates that excessive pusher fluid is
being produced, indicating a probable breakthrough of the
hot fluid along the exterior of the tubular member, the
packer 32 is then moved from its position to another loca-
tion along the tubular member 18. The move will probably
10 be toward the injection well and away from the production
well because of the initial position of the packer 32
closest to the production well 12. In the new position
some of the perforations 50 will be closed to injection,
others will be preferred for injection, and others that
15 previously functioned as injector perforations may now
function as producer perforations to provide a path for
produced petroleum and drive fluid through the tubular
member 18. While production of produced petroleum through
the perforations 50 in the horizontal portion 18 may carry
20 some sand with it from a tar sand formation, that sand
production will be inadequate to cause a sanding problem
in the tubular member.

By monitoring the ratio of produced petroleum
and pusher fluid and controlling the position of the
25 packer 32 within the tubular member 18 accordingly, it is
possible to maximize the production of petroleum and mini-
mize the production of pusher fluid.

Several variations in packer placement and con-
trol are contemplated. One variation is to place the
30 packer initially closer to the injector well and allow the
hot fluids to pass around the packer and along the tubular
member to heat the formation. As the entire formation
adjacent to the tubular member comes up to the temperature
where the viscous petroleum becomes mobile, the packer may
35 be moved toward the producer and the drive fluid is passed

01 out through the perforations to move the viscous
petroleum. Another alternative is to provide a series of
packers laterally along the horizontal portion of the
tubular member. The control mechanism then could control
05 the inflation and deflation of the several packers to
control heating of the formation and injection of the
drive fluid.

A further alternative to this technique of
diversion control is to plug, in a step-wise manner, the
10 horizontal perforated tubular member. Several feet of the
tubular member, farthest from the injection end, would be
cemented off subsequent to or immediately prior to drive
fluid breakthrough thus insuring that the drive fluid
would pass out through the clear perforations to move the
15 viscous crude toward the production well.

While the invention disclosed herein has been
described as operating in a tar sand petroleum-containing
formation, it should be understood that the invention is
not limited only to applications in tar sands. The method
20 described would work equally as well in other formations,
such as carbonates or bituminous sand deposits, for
instance the Grosmont Carbonate Reef in Canada or in the
bituminous sand formations in the United States, where
conventional drive processes are ineffective because of
25 virtually zero effective permeability of the formation.

While certain preferred embodiments of the
invention have been specifically disclosed, it should be
understood that the invention is not limited thereto as
many variations will be readily apparent to those skilled
30 in the art and the invention is to be given its broadest
possible interpretation within the terms of the following
claims.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method of assisting the recovery of viscous petroleum from a petroleum-containing formation comprising:
 - (a) forming a generally horizontal hole through a petroleum-containing formation;
 - (b) inserting a solid-wall, hollow tubular member into said generally horizontal hole to provide a continuous flow path through said formation;
 - (c) perforating said tubular member;
 - (d) flowing a hot fluid through the interior of said tubular member to heat viscous petroleum in said formation outside said tubular member to reduce the viscosity of at least a portion of the petroleum adjacent the outside of said tubular member to provide a potential passage for fluid flow through said formation adjacent the outside of said tubular member;
 - (e) positioning a movable diverter within said tubular member;
 - (f) injecting a drive fluid into said formation through said perforations and into said passage adjacent the outside of said tubular member to promote movement of the petroleum through said passage adjacent the outside of said tubular member to a recovery position for recovery from said formation;
 - (g) monitoring the production of petroleum and drive fluid at said recovery position;
 - (h) and positioning said diverter within said tubular member to selectively control the injection of drive fluid through said perforations to maintain said passage adjacent the outside of said tubular member and promote movement of said petroleum.

2. The method of Claim 1, wherein a substantially vertical injection well and a substantially vertical production well are drilled into said petroleum-containing formation and said generally horizontal hole is formed between and connecting said injection well and said production well.

3. The method of Claim 2 wherein said diverter is a settable, inflatable packer.

4. The method of Claim 3 wherein said diverter is positioned with a means passing into said tubular member in said generally horizontal hole from at least one of said injection well and said production well.

5. The method of Claim 4 wherein said diverter is initially positioned adjacent to said production well and moved toward said injection well through said tubular member in accordance with said monitored ratio of said hot fluid and petroleum at said recovery position.

6. The method of Claim 1 wherein said hot fluid and said drive fluid are steam and wherein the condition of at least said drive fluid steam is controlled in accordance with said monitored production of said petroleum and drive fluid at said recovery position.

7. The method of Claim 5 wherein said diverter is inflatable and deflatable and said inflation and deflation is controlled in accordance with the positioning of said diverter within said casing.

8. The method of Claim 1 wherein said perforations in said tubular member on one side of said diverter function as flow paths for said hot fluid and drive fluid into said forma-

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ation and on the other side of said diverter as flow paths for petroleum, hot fluid and drive fluid toward said recovery position depending upon the position of said diverter within said tubular member.

9. The method of Claim 5 wherein the effective position of said diverter within said tubular member is controlled in a series of positions away from and toward said production well to maintain hot fluid flow into said formation along said tubular member to maintain heating and movement of said heated, reduced viscosity petroleum to said recovery position, said movement of said diverter being in accordance with monitored ratio of said hot fluid and petroleum.

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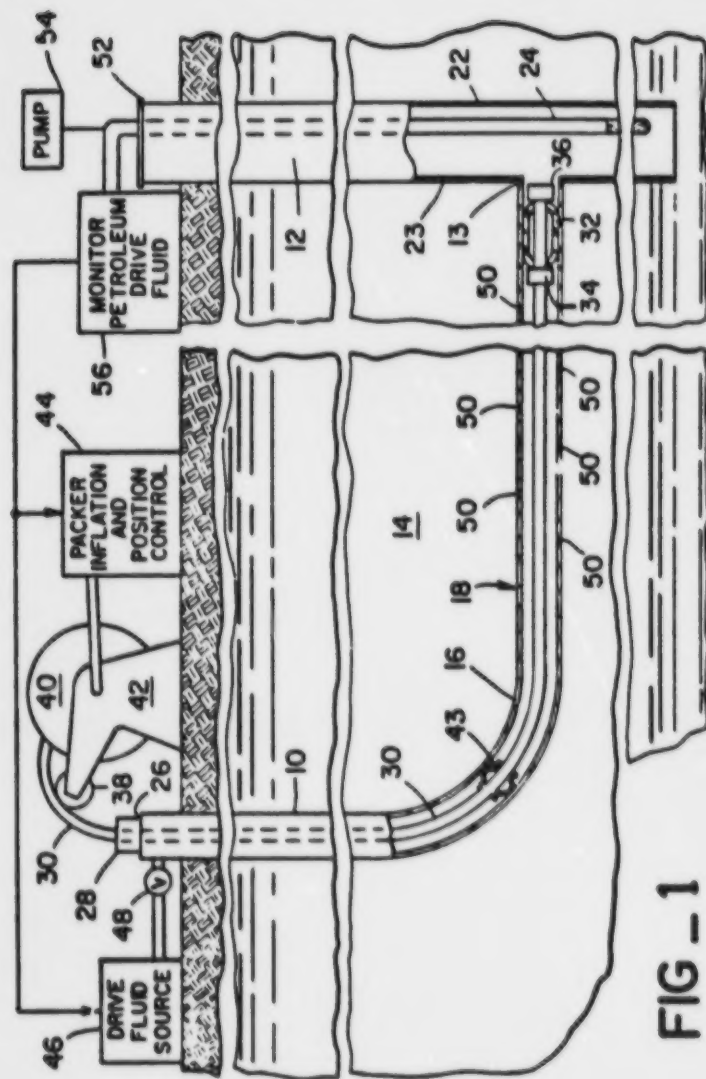


FIG -1

Patent Agents
S. A. L. & Co.

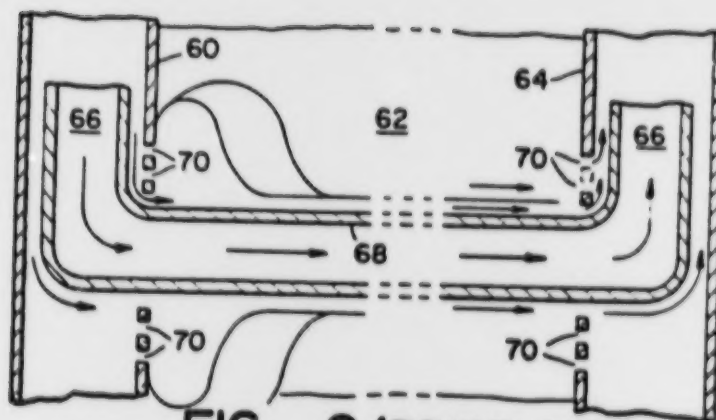


FIG. 2 (PRIOR ART)

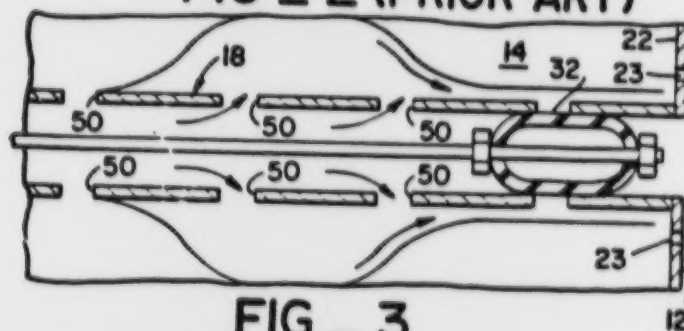


FIG. 3

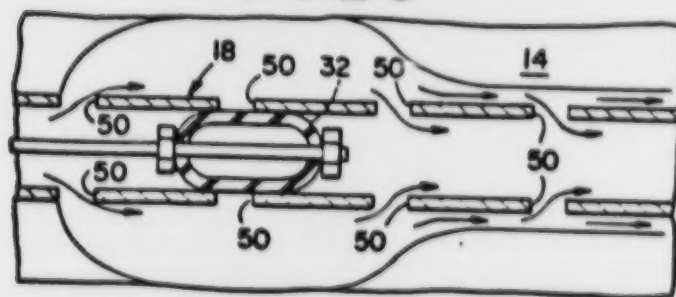


FIG. 4

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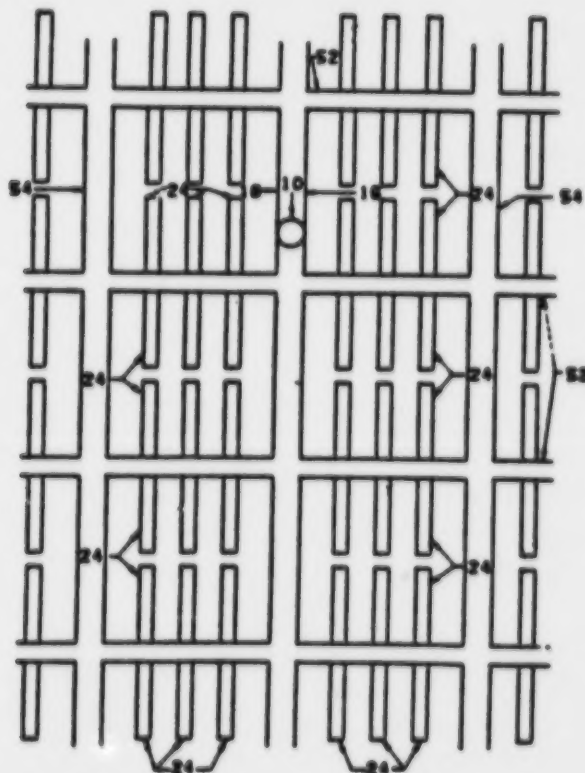
United States Patent [19]**Bouck et al.****[11] Patent Number: 4,463,988****[45] Date of Patent: Aug. 7, 1984****[54] HORIZONTAL HEATED PLANE PROCESS****[75] Inventors:** Larry S. Bouck; Erhan Oney; Richard E. Wershman, all of Tulsa, Okla.**[73] Assignee:** Cities Service Co., Tulsa, Okla.**[21] Appl. No.:** 415,286**[22] Filed:** Sep. 7, 1983**[51] Int. Cl.:** E21B 43/26; E21C 41/10**[52] U.S. Cl.:** 299/2; 299/19; 166/30; 166/272**[58] Field of Search:** 299/2, 18, 19; 166/30, 166/303, 272**[56] References Cited****U.S. PATENT DOCUMENTS**

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*Primary Examiner—Ernest R. Parker**Attorney, Agent, or Firm—Robert H. Sprinkle; George L. Roshon***[57]****ABSTRACT**

A process for in situ recovery of a tar sand deposit located beneath the earth's surface. A number of boreholes are drilled laterally from subsurface tunnels into the lower portion of the tar sands formation. Initially as a displacing means such as steam is injected into the boreholes, the tar sands become viscous and gravity flow into the bottom of the boreholes. Continuing to apply steam removes the tar sand deposits located in interstitial crevices between the boreholes thereby allowing the steam to flow laterally through these interstitial crevices to nearby boreholes. The steam rises toward the upper portion of the resource formation to create a horizontal heated plane of steam to further remove tar sand deposits located therein.

31 Claims, 10 Drawing Figures

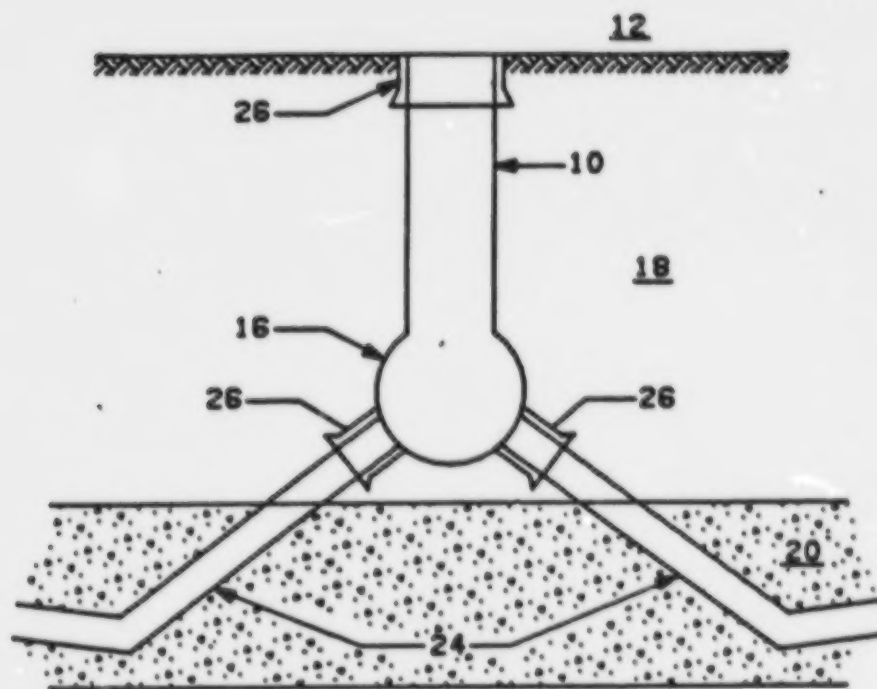


FIG. 1

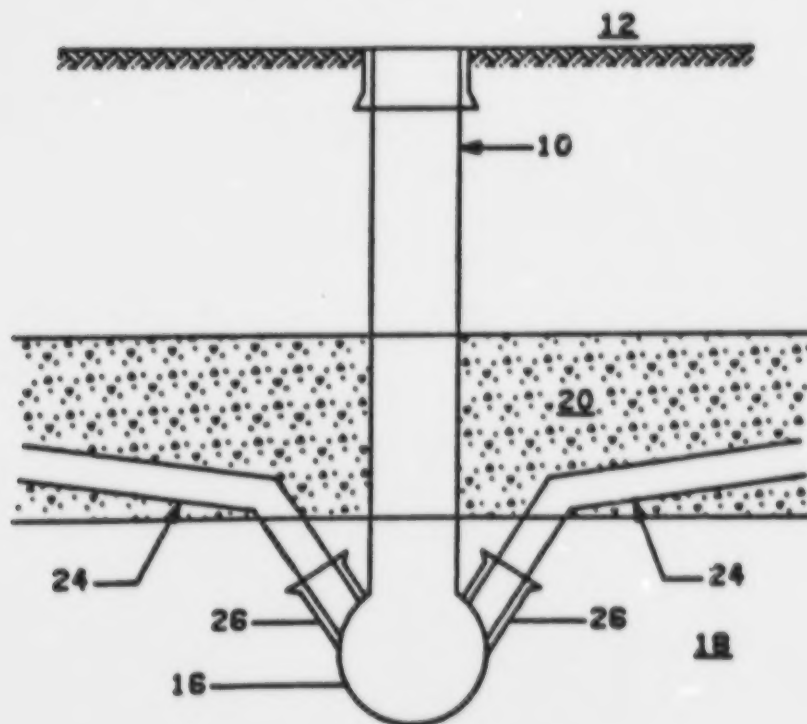


FIG. 2

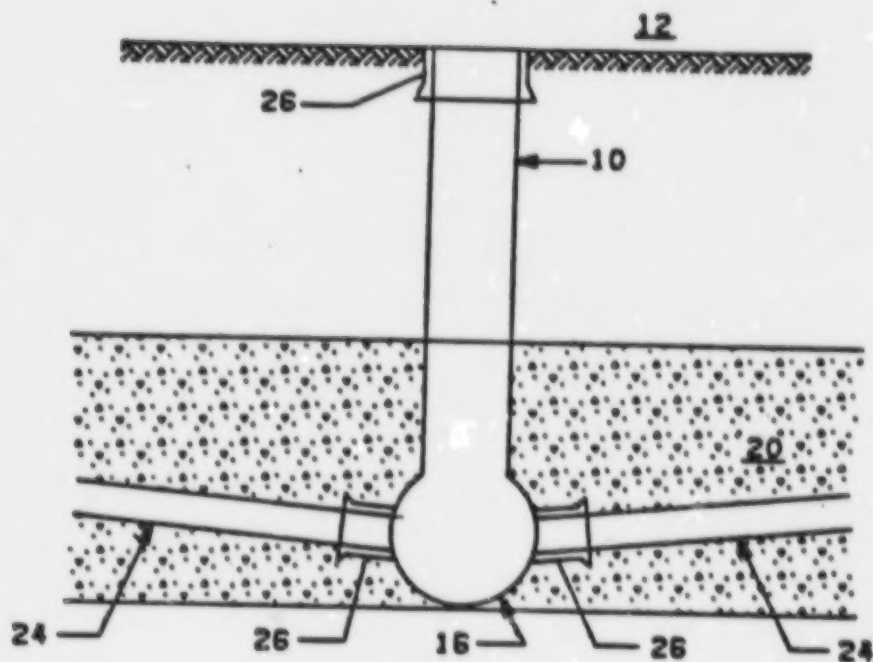


FIG. 3

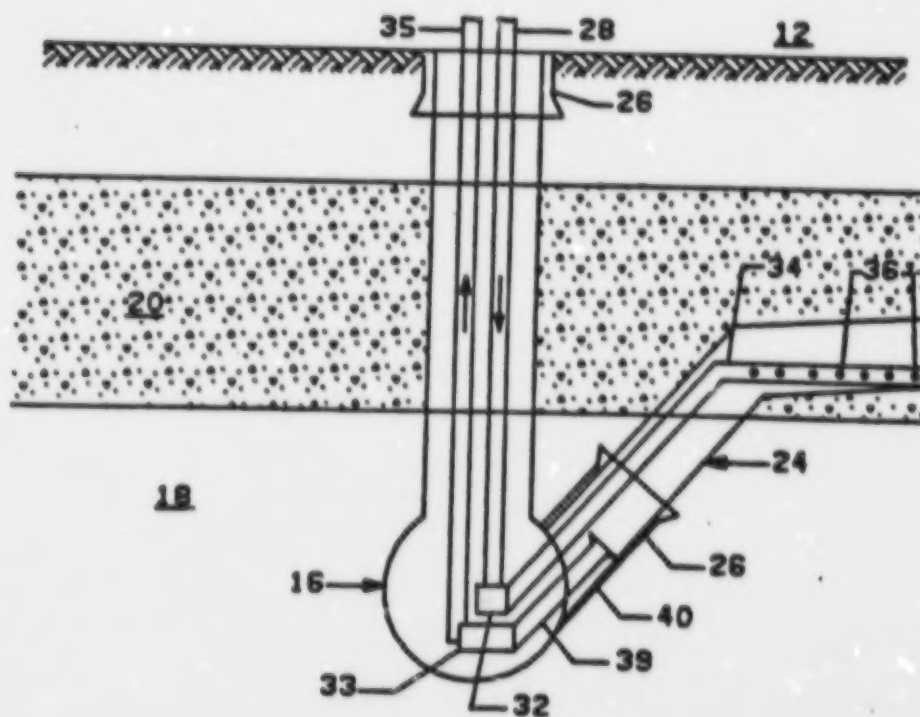


FIG. 4

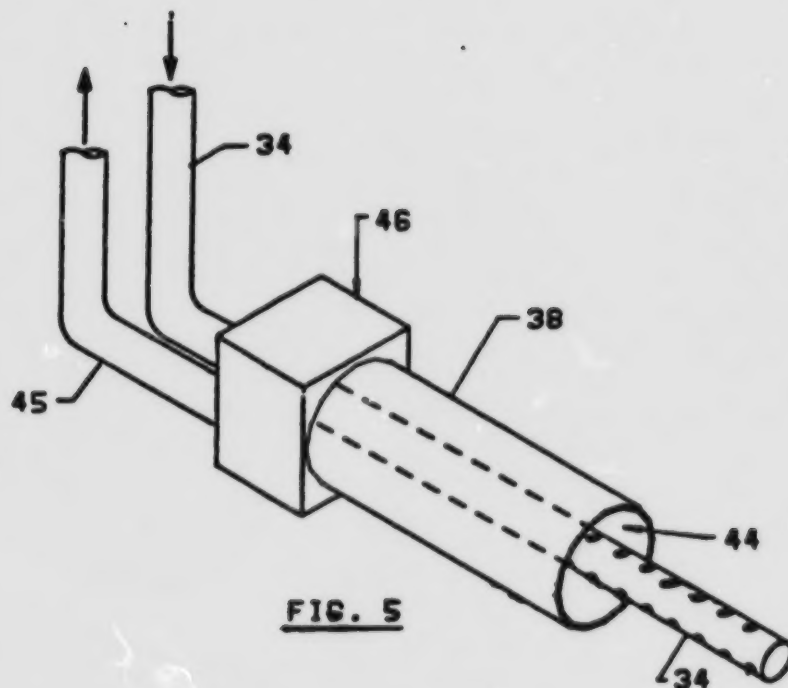


FIG. 5

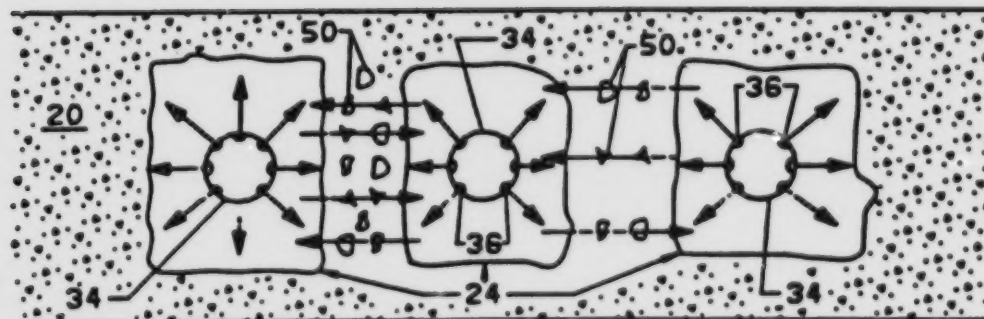


FIG. 6

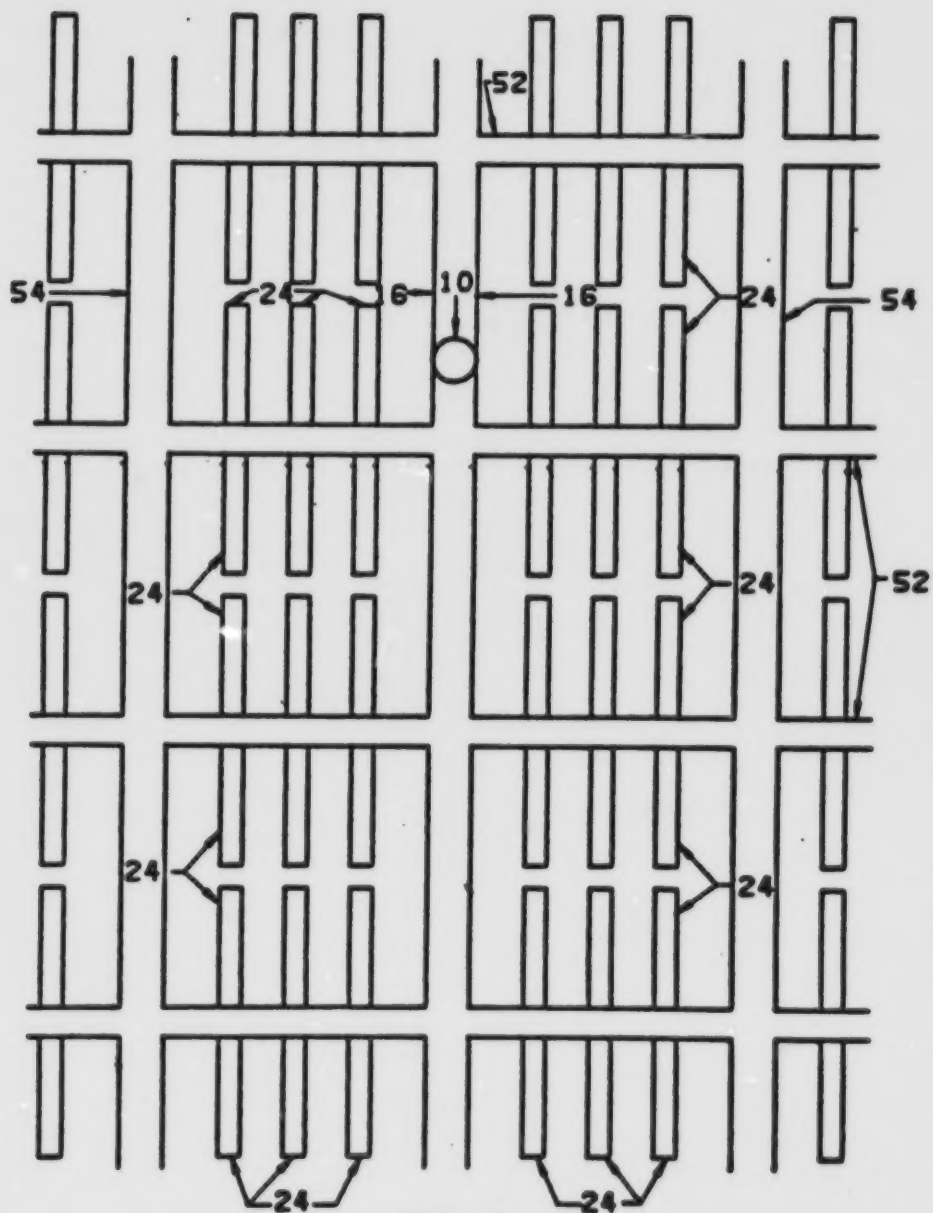


FIG. 7

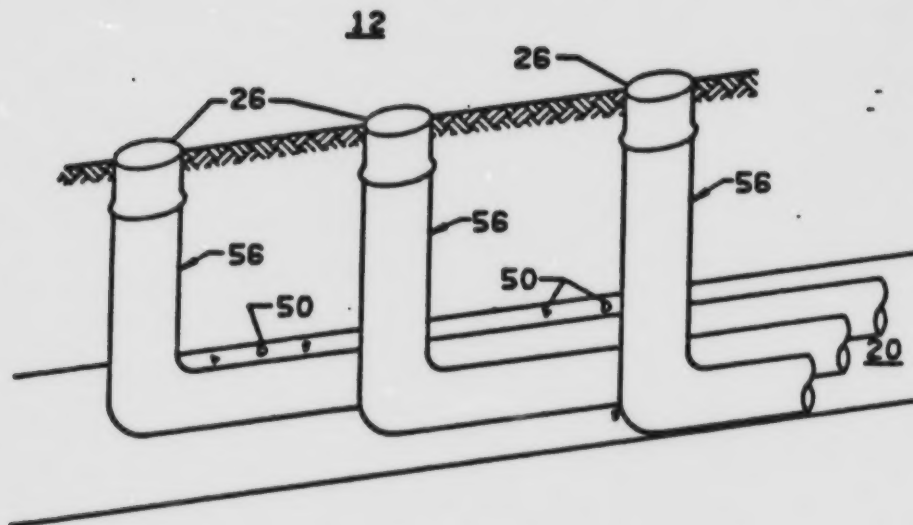


FIG. 8

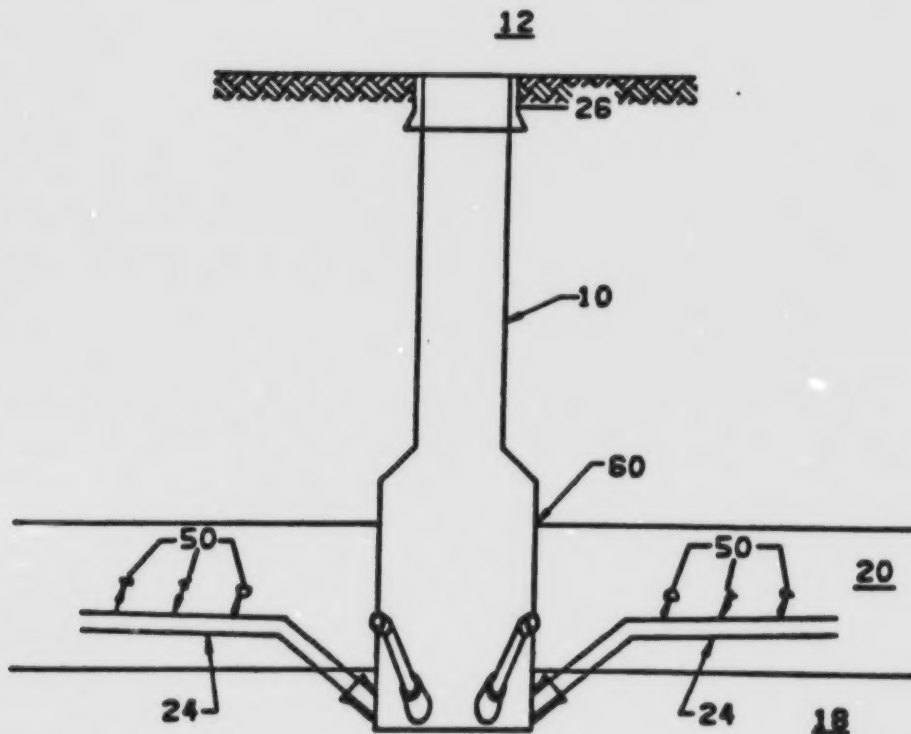


FIG. 9

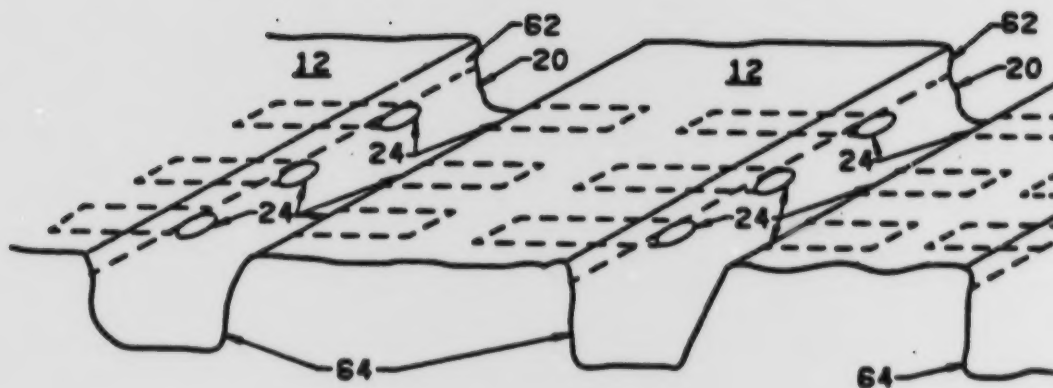


FIG. 10

HORIZONTAL HEATED PLANE PROCESS

BACKGROUND OF THE INVENTION

This invention relates to in situ recovery of a resource from a deep subsurface formation. More specifically, this invention provides a method for recovering a resource from a deep subsurface formation by creating a horizontal plane of heated displacing means between boreholes in the lower portion of the subsurface formation, resulting in an extensive surface area for heat transfer into the upper portion of the formation.

There are many methods for recovery of a resource such as tar sands from beneath the earth's surface. Where there is little overburden, surface mining techniques have been employed. However when the overburden is thick or the ratio of overburden to tar sands thickness is high, then surface mining is not economical. Many in situ recovery methods have been proposed. For the deeper buried tar sands reservoirs, wells are drilled from the earth's surface down into the tar sand formation. A broad range of methods has been devised to establish both a communication path through the heavy, highly viscous bitumen-filled sand and an efficient method to recover the bitumen from the sand. These methods, such as fracturing, steam injection, fire flooding, solvent flooding, gas injection and various combinations of these operational steps, involve the introduction of steam, gas or other displacing fluid by means of vertical holes drilled into or in proximity with the resource formation. These processes generally involve the heating of the resource formation to reduce the viscosity of the resource, thereby allowing removal of the resource from the formation by hydraulic means or gravity flow. U.S. Pat. No. 4,160,481 uses a plurality of boreholes radially extending from a central shaft to inject steam into the resource formation. The steam is injected into some of the boreholes to drive the resource into the remaining borehole where it is collected.

My invention, on the other hand, utilizes a horizontal heated plane of displacing means to greatly increase the exposure of the formation to the displacing means and thereby promote rapid and efficient transfer of heat to the resource. The horizontal heated plane is created by injecting heated displacing means into a plurality of boreholes within the resource formation. Unlike U.S. Pat. No. 4,160,481, heated displacing means is continuously added to the boreholes such that the resource in nearby boreholes is removed, thereby allowing the displacing means to laterally flow into nearby boreholes through the interstitial crevices between the boreholes vacated by the resource. The lateral flow of heated displacing means between the boreholes creates the most extensive surface area for heat transfer to the upper portion of the resource formation. The heated displacing means, such as steam, rises, condenses, and then drains, forming a local circulation cell. In addition, less heat is lost to the overburden since non-productive shales and sands above the tar sand will receive less heat from the process. When the heated zone reaches the height of the overburden, the process is nearly complete, and steam injection ceases in these boreholes thereby reducing the amount of heat transferred to the overburden.

In my invention, displacing means can be injected and removed from the boreholes simultaneously, thereby allowing the displacing means to be injected into all the boreholes at the same time if desired. By

injecting displacing means into as many boreholes as possible, a larger horizontal heated plane is created, resulting in greater and more efficient heat transfer to the resource. Therefore, what is needed and what has been invented by us is a method for in situ recovery of a resource from a subsurface formation without the foregoing deficiencies associated with the prior art methods.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a process for in situ recovery of a resource by heating the formation to increase the permeability of the resource.

It is another object of this invention to create a horizontal plane of heated displacing means across the lower portion of the subsurface formation in order to more efficiently heat the remainder of the subsurface formation.

It is yet another object of this invention to continuously inject heated displacing means into the boreholes while simultaneously removing resource production and displacing means from the boreholes.

These, together with various ancillary objects and features which will become apparent as the following description proceeds.

The present invention accomplishes its desired objects by broadly providing a method for in situ recovery of a subterranean resource. The invention comprises a horizontal heated plane process for in situ recovery of a resource from a subsurface formation. The process requires that the relative permeability of the resource be increased by the addition of heat thereto. The process comprises forming a plurality of lateral boreholes in the lower portion of the resource formation, injecting a displacing means into the boreholes in order to permeate the resource therein, causing the resource to become less viscous and to gravity flow (flow under the force of gravity) into the lower portion of the boreholes, and then continuing to inject displacing means into the boreholes such that the resource located in interstitial crevices between the boreholes is removed, allowing the displacing fluid to flow laterally through the interstitial crevices vacated by the resource into the adjacent boreholes. The heated displacing means rises towards the upper portion of the resource formation to create a horizontal heated plane of displacing means to remove the resource therein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevation view of a shaft extending to a location below the resource formation, a plurality of boreholes laterally extend from the access tunnel into the overlying competent formation;

FIG. 2 is an elevation view of a shaft extending to a location above the resource formation, a plurality of boreholes laterally extend from the access tunnel into the underlying competent formation;

FIG. 3 is an elevation view of a shaft extending into an area in proximity to the base of the resource formation, a plurality of boreholes laterally extend from the access tunnel into the resource formation;

FIG. 4 is a elevation view of the injection and evacuation piping extending through the shaft, production tunnels and boreholes;

FIG. 5 is a perspective view illustrating the annular area and assorted piping for collection and removal of

resource production and displacing fluid in a continuous controlled circulation system;

FIG. 6 is a cross-section view of the boreholes, illustrating the flow of displacing fluid between adjacent boreholes to create a horizontal heated plane of mobility;

FIG. 7 is an overhead view of the development illustrating the lateral boreholes, production tunnels, and main tunnels;

FIG. 8 is an elevation view of boreholes deviated to the horizontal in the resource formation;

FIG. 9 is an elevation view of a shaft terminating in an enlarged chamber which includes a plurality of radial boreholes extending from the chamber into the resource formation; and

FIG. 10 is a cross-section of a series of trenches excavated in the resource formation utilizing a plurality of lateral boreholes extending into the resource formation.

DETAILED DESCRIPTION OF THE INVENTION

Referring in detail now to the drawings wherein like or similar parts of the invention are identified by like reference numerals, FIG. 1 defines a shaft generally illustrated as 10 for access from the earth's surface 12 into the earth's subsurface. The diameter of shaft 10 must be sufficiently large to permit working personnel, drilling and support equipment to pass through shaft 10. Shaft 10 may be substantially vertical to earth's surface 12 as depicted in FIG. 1, or it may intersect the earth's surface 12 at any angle which will permit movement of personnel and equipment therethrough. Interconnecting with shaft 10 is the main access tunnel generally illustrated as 16. Main access tunnel 16 is drilled into a competent formation 18 located within the earth's subsurface, competent formation 18 having sufficient strength to support internal tunnelling therethrough. The competent formation 18 may be above the subsurface formation 20 containing the resource as depicted in FIG. 1, the competent formation 18 may lie below the resource subsurface formation 20 as depicted in FIG. 2, or the resource formation 20 may constitute the competent formation 18 as depicted in FIG. 3. Referring now to FIG. 1, wherein competent formation 18 lies above the resource formation 20, main access tunnel 16 is excavated in the competent formation 18 above the resource formation 20. A plurality of lateral boreholes, generally illustrated as 24, are drilled in a downward direction to a location in proximity to the bottom of resource formation 20 and then continued at a slight incline along the base of resource formation 20. Boreholes 24 are drilled to extend from opposite sides of main access tunnel 16 from about 30 feet to about 100 feet apart into the lower portion of resource formation 20. Preferably, boreholes 24 are drilled generally parallel to one another to provide a uniform distance between boreholes 24 for the displacing means to travel; however, where the density of the resource formation 20 varies, it may be desirable to vary the distance between boreholes 20 to compensate for the increased or decreased travel time of the displacing means between boreholes 20.

Boreholes 24 are started at 30° to 40° below the horizontal and drilled into resource formation 20 continuing until in proximity to the base of resource formation 20. Conductor pipe 26 is set and cemented into place in the competent formation to provide stability about the entrance to borehole 20. With pressure control, drilling

equipment and a pressurized mud system, boreholes 24 are then drilled to an approximate incline of about 5° above the horizontal and continued an additional 750 to 2000 feet.

When the competent formation 18 is below the resource formation 20, as depicted in FIG. 2, boreholes 24 are drilled outwardly from main access tunnel 16 30°-40° above the horizontal and continued until in proximity to the base of resource formation 20. The boreholes 24 are then continued for an additional 750 to 2000 feet at an incline of approximately 5° above the horizontal.

When the competent formation 18 and the subsurface resource formation 20 are the same, as depicted in FIG. 2, main access tunnel 16 is excavated near the base of resource formation 20. Boreholes 24 are drilled outwardly from main access tunnel 16 at approximately 750 to 2000 feet at a slight incline of approximately 5° above the horizontal.

After forming boreholes 24, a displacing means is injected into boreholes 24 in order to permeate the resource heated within resource formation 20 thereby causing the resource to become less viscous and to gravity flow with the displacing means to the bottom of borehole 24. The resource may consist of any formation deposit having a low initial relative permeability to a displacing means if introduction of heat will act upon the resource in such a manner so as to increase the relative permeability of the resource. The displacing means may consist of hot water or hot solvents, such as kerosene, naphtha, or a combination of these solvents and water. Steam is generally the most desirable displacing means because of its high heat content and high mobility. In the establishment of the horizontal heated plane, hot water, hot solvents or combinations thereof mixed with surfactants may be more desirable in order to insure the horizontal plane of communication fully develops before appreciable vertical channeling takes place. When full displacement of the horizontal heated plane results, improved sweep efficiency may be achieved by the introduction of inert gases, flue gas, air with steam, or any combination thereof with steam. At this later stage, it may be desirable to promote vertical permeability through the use of these gases to create vertical channels through the laminations of clay and shale to the upper portion of the resource formation 20.

Steam is introduced into boreholes 24 through a steam piping system depicted in FIG. 4. Steam generated at the surface flows down shaft riser pipes 28 to main access tunnel 16 and to a valve manifold 22 at the entrance to boreholes 24. The length of boreholes 24 are equipped with injection piping 34 through which steam may be distributed throughout borehole 24. Circumferential openings 36 along injection piping 34 distribute the steam over that portion of the borehole 24 extending within the resource formation 20 in order to obtain more uniform heating of the resource. Boreholes 24 also include a production gathering system consisting of an evacuation pipe means 38 the opening of which is located at the borehole opening 40 in order to collect the resource production as the production gravity flows down the inclined borehole 24 to the borehole opening 40. Evacuation pumps 23 collect and pump the production/water mixture through riser pipes 38 to the earth's surface 12 for further processing. Surface facilities (not shown in drawings) are required for steam production, electrical power generation, resource separation, water treatment and site services.

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In an alternate embodiment, depicted in FIG. 8, an injection piping 34 having a smaller diameter than evacuation piping 38, is located inside evacuation piping 38 such that their respective longitudinal axes are generally aligned. An annular area, generally illustrated as 44, comprising the area between the outer wall of injection pipe 34 and the inner wall of evacuation pipe 38 is used for the collection and removal of resource production, steam condensate and formation water. A manifold valve means 46 allows regulated withdrawal of these liquids through conduit 45. Displacing fluid is continuously injected into borehole 24 through injection pipe 34 while simultaneously removing resource production and displacing fluid from the lower portion of the borehole 24 through the annular area 44 of evacuation pipe 38 thereby resulting in a continuous controlled circulation of injection and evacuation.

Referring now to FIG. 6, after heated displacing fluid has been injected into boreholes 24, heating continues until considerable bitumen has been heated and removed from the formation rock 20 located between nearby boreholes 24. The viscous bitumen entrapped within the formation rock 20 is heated to reduce viscosity. The reduced viscosity bitumen then gravity flows to the bottom of boreholes 24 leaving small openings or interstitial crevices 50 in the formation previously occupied by the bitumen. A low steam pressure differential removes this remaining bitumen between nearby boreholes 24, allowing the steam to flow through the vacated interstitial crevices 50 to the other boreholes 24. The flow of displacing means between the boreholes 24 forms the horizontal heated plane of mobility. The horizontal heated plane constitutes a horizontal plane of heated displacing means which acts upwardly against resource formation 20 to blanket the under surface of resource formation 20. The blanketing effect, utilizing the natural tendency of heated displacing means to rise, thereby increases the area of coverage of the displacing means over the surface area of the resource formation 20. Displacing means is continuously injected into boreholes 24 until the remaining resource in the upper portion of the resource formation 20 has been dislodged from the formation and gravity drained to the bottom of borehole 24 for subsequent removal.

In order to aid heating of the resource, metal piping or liners 42 may be utilized in boreholes 24 as electrodes after proper insulation and connection to an AC power source (not shown in drawings). The flow of electrical current between metal liners 42 heats the water contained in the tar sand formation, thereby decreasing the amount of steam necessary to heat the bitumen in resource formation 20.

As steam injection proceeds resulting in the horizontal heated plane between boreholes 24, it is advantageous to stop introducing steam into certain of those boreholes 24 receiving steam indirectly through nearby boreholes 24. The reduction in the number of boreholes 24 receiving direct steam injection not only reduces the maintenance required for the steam injection and evacuation equipment, but it also reduces the amount of steam input, resulting in a more slowly rising arch of steam in resource formation 20. In order to increase thermal efficiency and to prevent heat loss, the terminated boreholes 24 may be sealed off at borehole opening 40 by a cement plug or other similar device.

In order to expand the tunnel network along one directional axis, a plurality of production tunnels, generally illustrated as 52 and depicted in FIG. 7, may be

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excavated to interconnect with the main access tunnel 16. The production tunnels 52 are formed such that the longitudinal axes of the production tunnels 52 are generally perpendicular to the longitudinal axis of main access tunnel 16. The distance between the longitudinal axis of adjacent production tunnels 52 is from about 1500 to about 4000 feet. The production tunnels 52 are of sufficient diameter to allow movement of drilling personnel and equipment through them. Boreholes 24 are then drilled in a lateral direction from production tunnels 52 extending into the lower portion of the resource formation 20 as previously described.

Referring still to FIG. 7, to further expand the tunnel network along another directional axis, main tunnels generally illustrated as 54 may be drilled to interconnect with the production tunnels 52 such that the longitudinal axes of the main tunnels 54 are generally parallel to the longitudinal axes of the main access tunnel 16. The main tunnels 54 are of sufficient diameter to permit movement of personnel and equipment through them. Generally the distance between the respective longitudinal axes of the main tunnels 54 is from about 3000 feet to about 5000 feet. The distance from the main access tunnel 16 to the first set of main tunnels 54 located on either side of the main access tunnel 16 is from about 1500 feet to about 2500 feet. Generally these main tunnels 54 will be repeated in parallel rows at intervals of about 3000 to 5000 feet along one directional axis to provide expansion of the tunnel network as the project area grows. Production tunnels 52 are interconnected with the main tunnels 54, the longitudinal axes of the production tunnels 52 being generally perpendicular to the longitudinal axes of the main tunnels 54. Boreholes 24 extend laterally from the production tunnels 52 into the lower portion of the formation 20.

In another embodiment of the invention as depicted in FIG. 8, a plurality of deviated boreholes generally illustrated as 56 are drilled from the earth's surface 12 into the lower portion of the resource formation 20. The boreholes 56 may start out at the earth's surface 12 nearly vertical but are then deviated as drilling proceeds into the earth's subsurface, to positions substantially aligned with the subsurface formation when near the base. Additional boreholes 56 are drilled generally parallel to and on the same horizontal plane as the initially drilled borehole 56 such that the longitudinal axes of the boreholes are from about 50 to about 200 feet apart. Heated displacing means such as steam is injected into boreholes 56. The displacing means reduces the viscosity of the resource entrapped within resource formation 20 causing the resource to gravity flow to the bottom of boreholes 56. As injection of displacing means continues, a horizontal heated plane of mobility is created between the boreholes 56 caused by the flow of displacing means through the vacated interstitial crevices 50. The displacing means and resource production is collected in a sump and pumped to the surface 12 by artificial lift means such as a surface tubing pump.

Another embodiment of the invention depicted in FIG. 9 includes a plurality of boreholes 24 radially extending from a chamber, generally illustrated as 60, like spokes of a wheel into the resource formation 20. A shaft 10 extends from the earth's surface 12 into the competent formation 18. The chamber 60 is a drilling and producing borehole constructed at the bottom of shaft 10. The boreholes 24 are drilled from chamber 60 into the lower portion of the resource formation 20 and extend approximately 2000 feet into resource formation

20 at a slight incline. Displacing means is then injected into the boreholes. As the resource is heated and becomes less viscous, it gravity flows to the bottom of radial boreholes 24. The heated displacing means forms a horizontal heated plane of mobility between the radial boreholes 24 when the displacing means flows between the boreholes 24 through the vacated interstitial crevices 80. Steam injected into these radial boreholes 24 creates a circular or square horizontal heated plane depending upon the particular pattern created by the radial boreholes 24.

Another embodiment of the invention as depicted in FIG. 10, comprises a plurality of trenches, generally illustrated as 64, dug into the earth's surface 12 through a thin overburden generally illustrated as 62. From trenches 64, a plurality of inclined lateral boreholes 24 are drilled approximately 2000 feet into the resource formation 20 at opposite sides of the trench 64. Preferably, boreholes 24 are drilled generally parallel to one another from about 30 to 100 feet apart. Heated displacing means is injected into the formation 20 through boreholes 24. After sufficient heating of the resource, a horizontal heated plane of mobility results between the boreholes 24.

While the present invention has been described herein with reference to particular embodiments thereof, a latitude of modification, various changes and substitutions are intended in the foregoing disclosure, and in some instances some features of the invention will be employed without a corresponding use of other features without departing from the scope of the invention.

We claim:

1. A horizontal heated plane process for in situ recovery of a resource from a subsurface resource formation comprising:

- (a) forming a plurality of lateral bore holes in the lower portion of the resource formation;
- (b) injecting a heated displacing means into said bore holes to permeate the resource therein causing the resource to become less viscous and gravity flow into the lower portion of said bore holes;
- (c) continuing to inject heated displacing means into said bore holes such that the resource located in interstitial crevices between said bore holes is removed, allowing the heated displacing means to flow laterally through the interstitial crevices vacated by the resource and into adjacent bore holes, and
- (d) allowing the heated displacing means to rise toward the upper portion of the resource formation to create a horizontal heated plane of communication, thus improving the removal of the resource therein.

2. The horizontal heated plane process for in situ recovery of a resource as recited in claim 1 additionally comprising discontinuing the injection of heated displacing means into at least one bore hole receiving heated displacing means through the vacated interstitial crevices.

3. The horizontal heated plane process for in situ recovery of a resource as recited in claim 2 additionally comprising closing off the entrance to at least one bore hole receiving heated displacing means from an adjacent bore hole.

4. The horizontal heated plane process for in situ recovery of a resource as recited in claim 3 additionally comprising:

- (a) injecting heated displacing means into said boreholes through an injection pipe inside said bore holes, said injection pipe having circumferential outlet holes along the longitudinal axis thereof; and
- (b) evacuating resource production and displacing means from the lower portion of said bore holes through an evacuation pipe, the larger diameter evacuation pipe positioned around and outside of the smaller diameter injection pipe such that the longitudinal axes of the evacuation pipe means and the injection pipe means are aligned to form an annular area between the outer wall of the injection pipe and the inner wall of the evacuation pipe for the collection and removal of the resource production and displacing means.

5. The horizontal heated plane process for in situ recovery of a resource as recited in claim 4 additionally comprising injecting heated displacing means continuously through said injection pipe while simultaneously removing resource production and displacing means from the lower portion of said bore holes through the annular area of said evacuation pipe.

6. The horizontal heated plane process for in situ recovery of a resource as recited in claim 1 wherein a competent formation lies generally below said subsurface resource formation.

7. The horizontal heated plane process for in situ recovery of a resource as recited in claim 1 wherein a competent formation lies generally above said subsurface resource formation.

8. The horizontal heated plane process for in situ recovery of a resource as recited in claim 1 wherein a competent formation and the subsurface resource formation are the same.

9. The horizontal heated plane process for in situ recovery of a resource as recited in claim 1 wherein:

- (a) the distance between the longitudinal axes of said bore holes is from about 30 feet to about 100 feet; and
- (b) the length of each bore hole is from about 750 feet to about 1500 feet.

10. A horizontal heated plane process for in situ recovery of a resource on a subsurface resource formation comprising:

- (a) forming at least one access means from the earth's surface into the earth's subsurface, said access means sized to permit movement of personnel and equipment therethrough;
- (b) forming one lateral main access tunnel in a competent formation such that said main tunnel is interconnected with said access means;
- (c) forming a plurality of bore holes laterally extending from said main tunnel into the lower portion of the resource formation;
- (d) injecting a heated displacing means into said bore holes to permeate the resource therein, causing the resource to become less viscous and gravity flow into the lower portion of said bore holes;
- (e) continuing to inject heated displacing means into said bore holes such that the resource located in interstitial crevices between the bore holes is removed, allowing the heated displacing means to flow laterally through the interstitial crevices vacated by the resource and into adjacent bore holes, and
- (f) allowing the heated displacing means to rise toward the upper portion of the resource formation to create a horizontal heated plane of communication.

tion, thus allowing heated displacing means to remove the resource therein.

11. A horizontal heated plane process for in situ recovery of a resource from a subsurface resource formation comprising:

- (a) forming at least one access means from the earth's surface into the earth's subsurface, said access means sized to permit movement of personnel and equipment therethrough;
- (b) forming one lateral main access tunnel in a competent formation such that said main tunnel is interconnected with said access means;
- (c) forming a plurality of lateral production tunnels interconnected with said main access tunnel;
- (d) forming a plurality of bore holes laterally extending from each said production tunnel into the lower portion of the resource formation;
- (e) injecting a heated displacing means into said bore holes to permeate the resource therein, causing the resource to become less viscous and gravity flow into the lower portion of said bore holes;
- (f) continuing to inject heated displacing means into said bore holes such that the resource located in interstitial crevices between the bore holes is removed, allowing the heated displacing means to flow laterally through the interstitial crevices vacated by the resource and into adjacent bore holes, and
- (g) allowing the heated displacing means to rise toward the upper portion of the resource formation to create a horizontal heated plane of communication and to remove the resource therein.

12. The horizontal heated plane process for in situ recovery of a resource as recited in claim 11 additionally comprising discontinuing the injection of heated displacing means from the production tunnels into at least one bore hole receiving heated displacing means through the vacated interstitial crevices.

13. The horizontal heated plane process for in situ recovery of a resource as recited in claim 12 additionally comprising closing off from the production tunnels at least one bore hole receiving heated displacing means through the vacated interstitial crevices.

14. The horizontal heated plane process for in situ recovery of a resource as recited in claim 11 additionally comprising inclining the bore holes above the horizontal, such that the longitudinal axes of the bore holes ascend from the junction where the bore holes interconnect with the production tunnels to allow the viscous resource in the lower portion of said bore holes to gravity flow into said production tunnels.

15. The horizontal heated plane process for in situ recovery of a resource as recited in claim 14 additionally comprising forming additional lateral main tunnels interconnecting with said production tunnels, each main tunnel positioned generally parallel to said main access tunnel.

16. The horizontal heated plane process for in situ recovery of a resource as recited in claim 15 wherein the distance between the longitudinal axes of said main tunnels is from about 3000 feet to about 5000 feet.

17. The horizontal heated plane process for in situ recovery of a resource as recited in claim 11 additionally comprising:

- (a) injecting the heated displacing means into said boreholes through an injection pipe inside said bore holes, said injection pipe means having circumfer-

ential outlet holes along the longitudinal axis thereof; and

- (b) evacuating resource production and displacing means from the lower portion of said bore holes through an evacuation pipe, the larger diameter evacuation pipe positioned around and outside of the smaller diameter injection pipe such that the longitudinal axes of the evacuation pipe and the injection pipe are aligned to form an annular area between the outer walls of the injection pipe and the inner wall of the evacuation pipe for the collection and removal of said resource production and displacing means.

18. The horizontal heated plane process for in situ recovery of a resource as recited in claim 17 additionally comprising injecting heated displacing means continuously through said injection pipe while simultaneously removing resource production and displacing means from the lower portion of said bore holes through the annular area of said evacuation pipe.

19. The horizontal heated plane process for in situ recovery of a resource as recited in claim 18 wherein the competent formation lies generally below the subsurface formation.

20. The horizontal heated plane process for in situ recovery of a resource as recited in claim 18 wherein the competent formation lies generally above the subsurface formation.

21. The horizontal heated plane process for in situ recovery of a resource as recited in claim 18 wherein the competent formation and the subsurface resource formation are the same.

22. The horizontal heated plane process for in situ recovery of a resource as recited in claim 18 wherein:

- (a) the distance between the longitudinal axes of said production tunnels is from about 1500 feet to about 4000 feet;
- (b) the distance between the longitudinal axes of said bore holes is from about 30 feet to about 100 feet; and
- (c) the length of said bore holes is from about 750 feet to about 1500 feet.

23. A horizontal heated plane process for in situ recovery of a resource from a subsurface resource formation comprising:

- (a) forming a plurality of bore holes from the earth's surface into the earth's subsurface;
- (b) deviating said bore holes such that said bore holes are generally aligned with and in proximity to the base of the subsurface formation;
- (c) injecting the heated displacing means into said bore holes to permeate the resource therein, causing the resource to become less viscous and gravity flow into a lower portion of said bore holes;
- (d) continuing to inject the heated displacing means into said bore holes such that the resource located in interstitial crevices between the bore holes is removed, allowing the heated displacing means to flow through the interstitial crevices vacated by the resource and into adjacent bore holes, and
- (e) allowing the heated displacing means to rise toward the upper portion of the resource formation to create a horizontal heated plane of communication and to remove the resource therein.

24. A horizontal heated plane process for in situ recovery of a resource from a subsurface formation, comprising:

- (a) forming at least one access means from the earth's surface into the earth's subsurface, said access means terminating in proximity to the subsurface formation, said access means sized to permit movement of personnel and equipment therethrough;
 - (b) forming a plurality of bore holes extending radially outward from said access means into the subsurface formation;
 - (c) injecting a heated displacing means into said bore holes in order to permeate the resource therein, causing the resource to become less viscous and gravity flow into the lower portion of said bore holes;
 - (d) continuing to inject the heated displacing means into said bore holes such that the resource located in interstitial crevices between the bore holes is removed, allowing the heated displacing means to flow through interstitial crevices vacated by the resource and into adjacent bore holes, and
 - (e) allowing the heated displacing means to rise toward the upper portion of the resource formation to create a horizontal heated plane of communication and to remove the resource therein.
23. The horizontal heated plane process for in situ recovery of a resource as recited in claim 23 or 24 additionally comprising discontinuing the injection of heated displacing means into at least one bore hole receiving heated displacing means through the vacated interstitial crevices.
24. The horizontal heated plane process for in situ recovery of a resource as recited in claim 23 additionally comprising closing off from the access means at least one bore hole receiving heated displacing means through the vacated interstitial crevices.
27. The horizontal headed plane process for in situ recovery of a resource as recited in claim 23 wherein the distance between the longitudinal axes of said bore holes is from about 30 feet to about 100 feet.

28. A horizontal heated plane process for in situ recovery of a resource from a shallow subsurface resource formation comprising:

- (a) forming a plurality of trenches into the shallow subsurface formation, said trenches sized to permit passage of personnel and equipment therethrough;
- (b) extending laterally a plurality of bore holes outwardly from said trenches into the subsurface resource formation;
- (c) injecting the heated displacing means into said bore holes in order to permeate the resource therein, causing said resource to become less viscous and gravity flow into the lower portion of said bore holes;
- (d) continuing to inject the heated displacing means into said bore holes such that the resource located in interstitial crevices between the bore holes is removed, allowing the heated displacing fluid to flow through the interstitial crevices vacated by the resource and into adjacent bore holes, and
- (e) allowing the heated displacing means to rise toward the upper portion of the resource formation to create a horizontal heated plane of communication and to remove the resource therein.

29. The horizontal heated plane process for in situ recovery of a resource as recited in claim 28 additionally comprising discontinuing the injection of heated displacing means into at least one bore hole receiving heated displacing means through the vacated interstitial crevices.

30. The horizontal heated plane process for in situ recovery of a resource as recited in claim 29 additionally comprising closing off from the trenches at least one bore hole receiving heated displacing means through the vacated interstitial crevices.

31. The horizontal heated plane process for in situ recovery of a resource as recited in claim 30 wherein the distance between the longitudinal axes of said bore holes is from about 30 feet to about 100 feet.

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(10) (CA) **CANADIAN PATENT** (12)

(54) In Situ Recovery of Viscous Materials

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Case 5562
CLR/nlh/ejl
10/14/81

BACKGROUND OF THE INVENTION

This invention relates to a method for the recovery of materials such as minerals and viscous hydrocarbons from subsurface earth formations. In a particular application
5 of the invention, the method relates to the in situ recovery of bitumen from tar sands or oil sands.

Various techniques have been considered for recovering bitumen from tar sand formations that are too deep for surface mining. These techniques typically involve raising
10 the temperature of the formation to reduce the viscosity of the bitumen, to assist in the separation of the bitumen from the sand matrix, and to promote movement of the liberated bitumen. The temperature can be raised by various means, such as electrical heating, fire flooding,
15 steam flooding, etc. Due to the high expenses and low recovery rates, these techniques typically have not been too successful.

There are also various types of mining techniques frequently used in the prior art to reach and process these
20 deep tar sands. Some of the techniques used involve drilling or excavating one or more vertical shafts into the tar sand formation and then extending lateral horizontal tunnels from the shaft. U.S. 4,160,481 discusses some of these techniques.

25 The inherent and expressed disadvantages of the prior art are overcome with the present invention.

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SUMMARY OF THE INVENTION

There are several embodiments involved in the present invention, and these generally involve different methods of entering and then thermally treating the tar sand formation. All of the embodiments involve a first step of drilling or excavating a borehole or shaft to the base of the subsurface formation to be exploited. Typically this formation is a tar sands or oil sands formation, but the technique can be used in other subsurface formations that comprise solid and semi-solid and viscous materials such as kerogen, high viscosity hydrocarbon materials such as heavy oils, inorganic ores, and the like.

The next step involves extension of the borehole or shaft below the base of the formation. This involves drilling or excavating into the stratum immediately below the formation to be exploited. This terminal end of the shaft or borehole, in the stratum below the desired formation, is then, optionally, enlarged to form an operating chamber below the base of the desired formation.

The next step involves the excavating of one or more tunnels extending laterally from this operating chamber in the stratum below the base of the formation.

The next step concerns the drilling of a plurality of second boreholes extending substantially upwardly and outward into the desired formation from these tunnels.

The above-listed steps are common to the first phase of the invention. Various embodiments of the invention are practiced by altering the succeeding steps.

For example, in one embodiment, steam is conducted down the first borehole or shaft and along the tunnel and

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thence injected into the plurality of second boreholes drilled from the tunnel. Or steam can be generated in the chamber and then injected via the tunnel into the plurality of boreholes. It is a feature of this embodiment that the steam used is at a pressure above the fracture pressure of the formation to be exploited. It is a characteristic of oil sands or similar hydrocarbon deposits that any flow channels in the formation matrix are effectively plugged with the solid or semisolid hydrocarbon material. The rate of injection for steam or any other heating medium at subfracture pressures would be too low to achieve the rate of heat input necessary to recover economically the hydrocarbon. Steam pressures above fracture pressure will permit high rates of injection. The injection of this steam is maintained for a time period resulting in an increase of the temperature of that portion of the formation surrounding the boreholes and the chamber. A "soaking" cycle can follow, for a discrete time period. When the pressure of the steam on the system is released, any liberated material of reduced viscosity can move, by gravity, and by means of the increased pressure due to the steam injection, to the lower portions of the second boreholes and thence via the tunnel to the lower portion of the chamber found in the stratum below the desired formation. The injection/production cycle is repeated until insufficient additional hydrocarbon is produced to warrant further cycles. The recovered viscous material can be moved to the surface, by means well-known in the art, for further processing.

The above-mentioned injection/production cycle is one of several methods for recovering heavy hydrocarbons from underground formations. In this invention, two recovery mechanisms are described and used.

5 One mechanism involves a stimulation process, such as by steam. This process involves a single well and is well-known in the art as "huff and puff," since steam is injected into a reservoir optionally remaining for a finite soaking period, and then allowed to vent back through the
10 entrance. Hydrocarbon production through the entrance is then noted. Several stimulation cycles may be needed for an appreciable outflow of desired material. The injection well and the production well are the same well, depending on the time during the stimulation process.

15 The other mechanism is called a "drive," and at least two wells are used. Here, for example, steam can be injected into one well, and, after a finite time, production is noted from a production well.

20 Pressure cycling, with variations in the steam pressure, can be used for either mechanism.

In another embodiment, steam, at a pressure above the fracture pressure of the formation to be exploited, is injected into the boreholes, as in the above-described embodiment, continuing the injection/ production cycles
25 until the viscous material between the wells is made mobile, stopping the steam flow into the injector wells, completing selected second boreholes as producer wells, initiating a flooding procedure, exemplified by a fire flood, water flood, steam flood, emulsion flood, or solvent
30 flood, flowing from injector wells to production wells, and

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collecting the liberated material of reduced viscosity as before.

In another embodiment, after the second boreholes are extended substantially upward and outward into the desired formation from the tunnels, some of these second boreholes are completed as injector wells, and the remainder of the second boreholes are completed as producer wells. Then steam, at or above fracturing pressure, is injected into the second boreholes completed as injector wells. A number of injection/production cycles are carried out so as to increase the temperature of that portion of the formation surrounding the boreholes. The steam flow into the boreholes designated as injector wells is then stopped, and a flooding procedure is initiated, using the same or a different procedure from the choices noted above, such that the flooding material flows from injector wells to producer wells. The liberated material of reduced viscosity is then collected as before.

In a further embodiment of the invention, steam, at a pressure above fracturing pressure of the desired formation, is injected into the second boreholes, as the beginning of a stimulation phase. The injection/production cycles of steam stimulation are continued for some time so as to increase the temperature of the surrounding formation.

Selected second boreholes are completed as producer wells, and a steam flood is then initiated, with the variation that the steam pressure is cyclically varied. Following steps in the procedure are as previously described.

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In another embodiment, after the second boreholes are drilled from the chamber into the desired formation, some of these second boreholes are completed as injector wells and the remainder are completed as producer wells. Then steam, at a pressure above the fracturing pressure, is injected into the boreholes comprising the injector wells. The previously-described injection/production cycles are carried out, resulting in a temperature increase of the surrounding formation. A steam flood is then initiated, with the modification that the steam pressure is cyclically varied during the flooding. The steam pressure can be varied from about atmospheric to the operating pressure. Liberated hydrocarbon material is then treated as discussed above.

The embodiments discussed above have one or more of the advantages discussed below.

A central shaft, with associated tunnels and boreholes, has the advantages over wells drilled from the surface of:

- (a) reduced drilling costs,
- (b) horizontal wells or boreholes are easier to drill,
- (c) there is less heat loss between the surface and the tar sands or oil sands, formation, or reservoir, and
- (d) the movement of recovered oil from the formation to the surface is more efficient than when wells are drilled from the surface.

The advantages of continuing the shaft or borehole into the zone below the formation or reservoir include:

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- (a) increased safety, since an operating chamber and the tunnels are formed in the zone below the formation,
 - (b) wells can be cemented in the zone below the formation, while there is great difficulty in cementing wells in an oil sands or tar sands formation, and
 - (c) it is easier and safer to complete wells that have their beginning or terminus in the tunnels below the formation.
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15 The advantage of using tunnels from the central shaft as the starting point for the boreholes, rather than drilling the boreholes radially outward from the shaft, is that the boreholes can be drilled parallel to one another; giving a more uniform coverage of the reservoir. The rectangular layout with tunnels is also more amenable to a repeated pattern.

20 Using a steam pressure greater than the fracturing pressure of the formation allows injection of the steam into the formation or reservoir at a sufficient rate to recover the hydrocarbon product economically. The greater pressure also allows a higher percentage of the formation or reservoir to be contacted, and this gives a higher usage efficiency for the injected steam. This greater pressure
25 also allows a greater percentage of the formation to be processed.

Cyclical operation involving varying the steam pressure improves the recovery of the product and offers an improved oil/steam ratio. The "cycles" can vary in time
30 from about 10 to about 50 hours, from peak to peak.

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Other advantages of the embodiments of the process will be noted by those who are skilled in the arts involved in this process.

DESCRIPTION OF THE DRAWINGS

- 5 Figure 1 shows a side view of the first borehole extending below the base of the formation and into the underburden, with a tunnel extending normal to the borehole and secondary boreholes extending normal to the tunnel and upwardly into the desired formation.
- 10 Figure 2 shows a top view of the first borehole, the tunnel, and the secondary boreholes.

DETAILED DESCRIPTION OF THE INVENTION

The described process for the in situ recovery of viscous materials can be used where the desired formation
15 or reservoir is greater than about 30 meters from the surface. For example, the invention is operable where the formation or reservoir is from about 90 to about 900 meters below the surface.

The thickness of the subsurface formation can vary,
20 such as from about 1 m to about 300 m, depending on the geology at that location. Formations thicker than about 5 m. are more economical to work.

In order to reduce the viscosity of, for example, the tar sands or oil sands found in the formation an operating
25 temperature of about 40°C or higher is desirable. The temperature of saturated steam at the injection pressure in

the formation will give a gradient of operating temperatures, being highest near the injection nozzle and becoming lower as the distance from the injection nozzle increases.

The quality of the steam used for injection can vary
5 from about 50% to about 100%. The injection pressure used should be of the order of about 17 kPa/m or more, preferably from about 22 to about 44 kPa per meter of depth. The steam injection rate should be about the water equivalent of 15 m³/d/well or more, preferably from about 80 to about
10 350 m³/d/well.

The number of vertical shafts penetrating the overburden, and the material underlying the formation will depend on the size of the deposit and the desired production rate. The minimum number is 1, while a preferred or
15 working number can vary between about 4 and about 25.

The number of tunnels starting from each shaft can vary from 1 to 9 depending on the desired layout. The preferred number is 1 or 2. The length of each tunnel will normally be established by ventilation requirements.

20 Figure 1 illustrates a simplified cross-section view of an in situ operation. A shaft, or first borehole 2, is sunk through overburden 1 into the desired formation 3. The borehole is continued below the base of formation 3, into the underburden 4. Tunnel 5 is formed at the base of, and normal to, the first borehole 2. From this tunnel,
25 second boreholes 6 are drilled upwardly and radially outwardly, to penetrate formation 3. Casing 7 is used to reduce the probability of collapse of borehole 6. One embodiment of production tubing (borehole 6 completed as a
30 producing well) is shown as 8. Some known method of moving

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material liberated from the borehole to the surface, such as a pump, is not shown.

Figure 2 shows how tunnel 2 is formed relative to the first borehole 1. Second boreholes 3 are typically formed
5 normal to tunnel 2.

The stimulation injection time should be 5 days or more, such as from about 10 to about 100 days. The stimulation cycles are 1 or more, such as from about 5 to about 25.

10 The number of second boreholes, varying in number from about 2 to about 200 and extending upwardly and outwardly from the tunnels into the hydrocarbon-bearing formation, can vary with the length of the tunnels, with spacing of about 5 to about 300 m, preferably from about 8 to about
15 200 m. The length of these second boreholes can vary from a few meters, such as about 3, to a length that will allow connection with another, distant well, after the temperature of the intervening formation has been raised to allow movement of the desired material, such as a viscous hydro-
20 carbon. This latter distance may vary from about 50 m to about 600 m.

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CLAIMS

1. A method for the in-situ recovery of viscous materials from a subsurface formation, comprising:

- 5 a) forming a first borehole to the base of the subsurface formation to be exploited,
- b) extending the borehole below the base of the formation,
- 10 c) extending one or more tunnels from the lower end of the borehole of step (b) into the underburden below the base of the desired formation.
- d) drilling a plurality of second boreholes extending substantially upwardly and outwardly into said formation from the tunnel(s) of step (b),
- 15 e) injecting steam into said second boreholes, with the steam having a pressure above the fracture pressure of the subsurface formation,
- 20 f) maintaining the injection of step (e) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 25 g) releasing the pressure on the system of second boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portions of said second boreholes and

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thence to the lower portion of the first borehole,

- h) collecting the liberated material, and
- i) repeating the injection/production cycle of steps (e)-(h).

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2. The method of claim 1 wherein:

- a) the subsurface formation containing viscous materials is approximately 30m or more below the surface,
- b) the lower portion of the borehole or shaft is enlarged to form an operating chamber below the base of the formation,
- c) the number of tunnels varies from 1 to about 9,
- d) the spacing of the second boreholes varies from about 3 to about 300 m,
- e) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa, per meter of depth from the surface, and a steam injection rate at a water equivalent of greater than 15 m³/d/well,
- f) the injection time period of step (d) is at least 3 days, and
- g) the repeated injection/production cycles of step (h) number at least two.

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3. The method of claim 2, wherein:

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- a) the number of second boreholes varies from about 2 to about 200,
 - b) the steam injection rate has a water equivalent of from about 80 to about 350 m³/d/well,
 - c) the injection time period can vary from about 10 to about 100 days, and
 - d) the repeated injection/production cycles can number from about 2 to about 25.
- 10 4. A method for the in situ recovery of viscous materials from a subsurface formation, comprising:
- 15
- a) forming a first borehole to the base of the subsurface formation to be exploited,
 - b) extending the borehole below the base of the formation,
 - c) extending one or more tunnels horizontally outwardly from the borehole of step (b), below the base of the formation,
 - d) drilling a plurality of second boreholes extending substantially upwardly and outwardly into said formation from the tunnel(s) of step (c),
 - e) injecting steam into said second boreholes, with the steam having a pressure above the fracture pressure of the subsurface formation,
 - f) maintaining the injection of step (e) for a time period so as to increase the temperature of that portion of the formation
- 20
- 25

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surrounding said second boreholes and any fracture fissures formed by the injection,

g) releasing the pressure on the system of boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the second boreholes and thence to the lower portion of the first borehole,

h) collecting the liberated material,

i) repeating the injection/production cycle until the viscous material between at least some of the second boreholes is made mobile,

j) stopping the steam flow into the second boreholes,

k) completing selected second boreholes as producer wells,

l) initiating a flooding procedure, selected from the procedures consisting of fire flood, water flood, steam flood, emulsion flood, and solvent flood, flowing from at least one injector well to at least one producing well, and

m) collecting the liberated material.

3. The method of claim 4, wherein:

a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,

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- 5
- b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
- c) the number of tunnels varies from 1 to about 9,
- d) the spacing of second boreholes varies from about 5 to about 300 m,
- 10 e) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa, per foot of depth from the surface, and a steam injection rate at a water equivalent of greater than $15 \text{ m}^3/\text{d}/\text{well}$,
- 15 f) the injection time period of step (f) is at least 5 days, and
- g) the repeated injection/production cycles of step (i) number at least two.
6. The method of claim 5, wherein:
- 20 a) the number of the second boreholes varies from about 2 to about 200,
- b) the steam injection rate has a water equivalent of from about 80 to about $350 \text{ m}^3/\text{day}/\text{well}$,
- 25 c) the injection time period can vary from about 10 to about 100 days, and
- d) the repeated injection/production cycles can number from about 2 to about 25.

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7. A method for the in-situ recovery of viscous materials from a subsurface formation, comprising:

- a) forming a first borehole to the base of the subsurface formation to be exploited,
- 5 b) extending the borehole below the base of the formation,
- c) extending one of more tunnels horizontally outwardly from the borehole of step (b), below the base of the formation,
- 10 d) drilling a plurality of second boreholes extending substantially upwardly and outwardly into said formation from the tunnel(s) of step(c),
- 15 e) completing at least one of said second boreholes as an injector well, while completing the remainder of said second boreholes as producer wells,
- 20 f) injecting steam into said second boreholes completed as injector wells, with the pressure of the steam above the fracture pressure of the subsurface formation,
- 25 g) maintaining the injection of step (e) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 30 h) releasing the pressure on the system of injector boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the first borehole,

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- i) repeating the injection/production cycle of steps (f)-(h) until hydrocarbon between at least some of said second boreholes is mobilized,
- 5 j) stopping the steam flow to the injector well,
- k) initiating a flood procedure, selected from the procedures consisting of fire flood, water flood, steam flood, emulsion flood,
- 10 solvent flood, flowing from an injector well to a producer well, and
- l) collecting the liberated material.

8. The method of claim 7, wherein:

- 15 a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
- 20 c) the number of tunnels varies from 1 to about 9,
- d) the spacing of the second boreholes varies from about 5 to about 300 m,
- 25 e) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa, per meter of depth from the surface, and a steam injection rate at a water equivalent of greater than 15 m³/d/well.

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- f) the injection time period of step (g) is at least 5 days, and
- g) the repeated injection/production cycles of step (h) number at least two.

5 9. The method of claim 8, wherein:

- a) the number of second boreholes varies from about 2 to about 200,
- b) the steam injection rate has a water equivalent of from about 80 to about 350 m³/d/well,
- 10 c) the injection time period can vary from about 10 to about 100 days, and
- d) the repeated injection/production cycles can number from about 2 to about 25.

15 10. A method for the in situ recovery of viscous materials from a subsurface formation, comprising:

- a) forming a first borehole to the base of the subsurface formation to be exploited,
- b) extending the borehole below the base of the formation,
- 20 c) extending one or more tunnels horizontally outwardly from the borehole of step (b), below the base of the formation,
- d) drilling a plurality of second boreholes
- 25 extending substantially upwardly and outwardly into said formation from the tunnel(s) of step (c),

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- e) injecting steam into said second boreholes, with the steam having a pressure above the fracture pressure of the subsurface formation,
- 5 f) maintaining the injection of step (e) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 10 g) releasing the pressure on the system of second boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of said second boreholes and thence to the lower portion of the first borehole.
- 15 h) collecting the liberated material,
- i) repeating the injection/production cycle until the viscous material between at least some of the second boreholes is mobilized,
- 20 j) stopping the steam flow,
- k) completing selected second boreholes as producer wells,
- l) initiating a steam flooding procedure,
- m) cyclically varying the steam pressure during the operation of step (l), and
- 25 n) collecting the liberated material.

11. The method of claim 10, wherein:

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- 5 a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation.
- c) the number of tunnels varies from 1 to about 9,
- 10 d) the spacing of the second boreholes varies from about 5 to about 300 m,
- e) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa, per foot of depth from the surface, and a steam injection rate at a water equivalent of greater than 15 m³/day/well,
- 15 f) the pressure of step (m) varies from about atmospheric to the operating pressure,
- g) the injection time period of step (f) is at least 5 days, and
- 20 h) the repeated injection/production cycles of step (i) number at least two.
12. The method of claim 11, wherein
- 25 a) the number of the second boreholes varies from about 2 to about 200,
- b) the steam injection rate has a water equivalent of from about 80 to about 350 m³/d/well,

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- c) the injection time period can vary from about 10 to about 100 days, and
- d) the repeated injection/production cycles can number from about 2 to about 25.

5 13. A method for the in situ recovery of viscous materials from a subsurface formation, comprising:

- a) forming a first borehole to the base of the subsurface formation to be exploited,
- 10 b) extending the borehole below the base of the formation,
- c) extending one or more tunnels horizontally outwardly from the borehole of step (b), below the base of the formation,
- 15 d) drilling a plurality of second boreholes extending substantially upwardly and outwardly into said formation from the tunnel(s) of step (c),
- e) completing at least one of said second boreholes as an injector well, while completing
20 the remainder of said second boreholes as producer wells,
- f) injecting steam into said second boreholes designated injector wells, with the steam having a pressure above the fracture pressure of the subsurface formation,
- 25 g) maintaining the injection of step (f) for a time period so as to increase the temperature of that portion of the formation

- surrounding said second boreholes and any fracture fissures formed by the injection,
- h) releasing the pressure on the boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the first borehole,
- i) repeating the injection/production cycle until hydrocarbon between at least some of said second boreholes is mobilized,
- j) initiating a steam flooding procedure,
- k) cyclically varying the steam pressure during the operation of step (i), and
- l) collecting the liberated material.
14. The method of claim 13, wherein:
- a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
- c) the number of tunnels varies from 1 to about 9,
- d) the spacing of the second boreholes varies from about 5 to about 300 m,
- e) the injection steam has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa, per meter of depth from the surface, and a steam

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injection rate at a water equivalent of greater than $15 \text{ m}^3/\text{d}/\text{well}$.

- 5
- f) the steam pressure of step (k) varies from about atmospheric to the operating pressure,
 - g) the injection time period of step (g) is at least 5 days, and
 - h) the repeated injection/production cycles of step (h) number at least two.

13. The method of claim 14, wherein:

- 10
- a) the number of the second boreholes varies from about 2 to about 200,
 - b) the steam injection rate has a water equivalent of from about 80 to about $350 \text{ m}^3/\text{d}/\text{well}$,
- 15
- c) the injection time period can vary from about 10 to about 100 days, and
 - d) the repeated injection/production cycles can number from about 2 to about 25.

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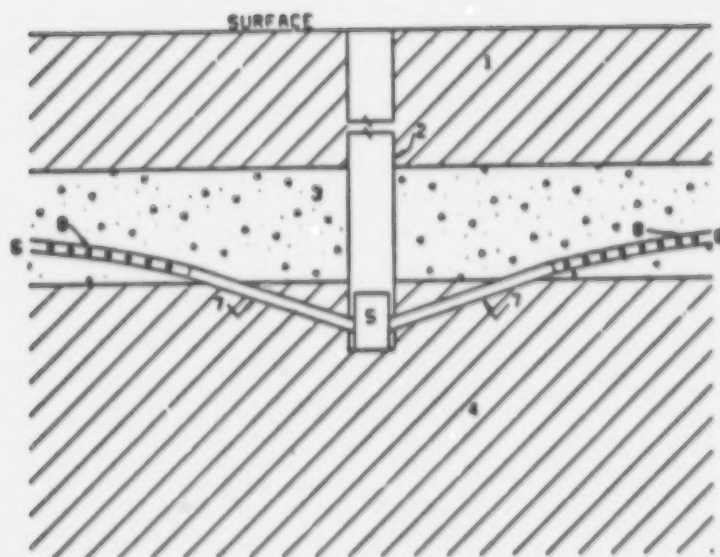


FIG. 1

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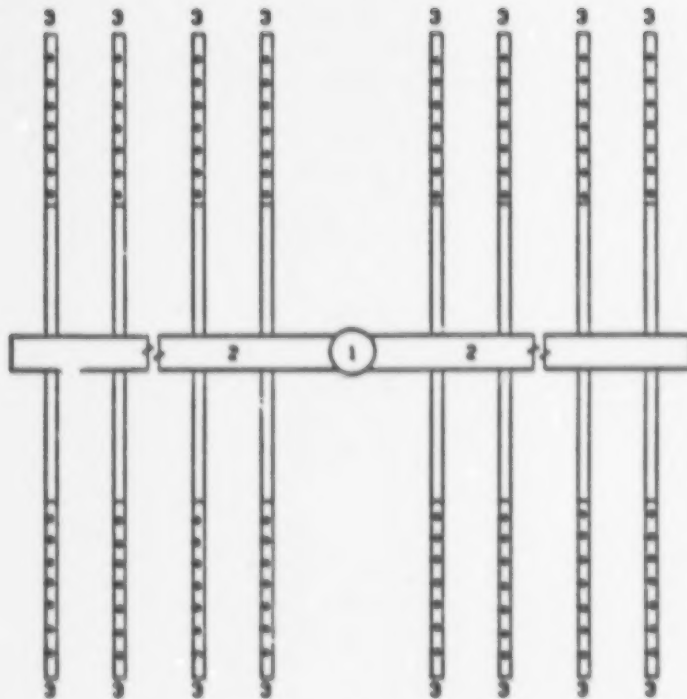


FIG. 2

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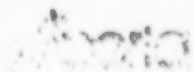


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(54) In Situ Recovery of Viscous Materials

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(73) Granted to Canada Cities Service Limited
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Canada

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BACKGROUND OF THE INVENTION

This invention relates to a method for the recovery of materials such as minerals and viscous hydrocarbons from subsurface earth formations. In a particular application of the invention, the method relates to the in situ recovery of bitumen from tar sands or oil sands.

Various techniques have been considered for recovering bitumen from tar sand formations that are too deep for surface mining. These techniques typically involve raising the temperature of the formation to reduce the viscosity of the bitumen, to assist in the separation of the bitumen from the sand matrix, and to promote movement of the liberated bitumen. The temperature can be raised by various means, such as electrical heating, fire flooding, steam flooding, etc. Due to the high expenses and low recovery rates, these techniques typically have not been too successful.

There are also various types of mining techniques frequently used in the prior art to reach and process these deep tar sands. Some of the techniques used involve drilling or excavating one or more vertical shafts into the tar sand formation and then extending lateral horizontal tunnels from the shaft. U.S. 4,160,481 discusses some of these techniques.

The inherent and expressed disadvantages of the prior art are overcome with the present invention.

SUMMARY OF THE INVENTION

There are several embodiments involved in the present invention, and these generally involve different methods of

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entering and then thermally treating the tar sand formation. All of the embodiments involve a first step of drilling or excavating a borehole or shaft to the base of the subsurface formation to be exploited. Typically this
5 formation is a tar sands or oil sands formation, but the technique can be used in other subsurface formations that comprise solid and semisolid and viscous materials such as kerogen, high viscosity hydrocarbon materials such as heavy oils, inorganic ores, and the like.

10 The next step involves extension of the borehole or shaft below the base of the formation. This involves drilling or excavating into the stratum immediately below the formation to be exploited. This terminal end of the shaft or borehole, in the stratum below the desired formation, is then, optionally, enlarged to form an operating
15 chamber below the base of the desired formation.

The next step concerns the drilling of a plurality of second boreholes extending substantially upwardly and radially outward into the desired formation from this operating chamber.
20

The above-listed steps are common to the first phase of the invention. Various embodiments of the invention are practiced by altering the succeeding steps.

For example, in one embodiment, steam is conducted
25 down the first borehole or shaft and thence injected into the plurality of second boreholes drilled from the operating chamber. Or steam can be generated in the chamber and then injected into the plurality of boreholes. It is a feature of this embodiment that the steam used is at a
30 pressure above the fracture pressure of the formation to be

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5 exploited. It is a characteristic of oil sands or similar hydrocarbon deposits that any flow channels in the formation matrix are effectively plugged with the solid or semi-solid hydrocarbon material. The rate of injection for steam or any other heating medium at subfracture pressures would be too low to achieve the rate of heat input necessary to recover economically the hydrocarbon. Steam pressures above fracture pressure will permit high rates of injection. The injection of this steam is maintained for a time period resulting in an increase of the temperature of that portion of the formation surrounding the boreholes and the chamber. A "soaking" cycle can follow, for a discrete time period. When the pressure of the steam on the system is released, any liberated material of reduced viscosity can move, by gravity, and by means of the increased pressure due to the steam injection, to the lower portions of the second boreholes and thence to the lower portion of the chamber found in the stratum below the desired formation. The injection/production cycle is repeated until insufficient additional hydrocarbon is produced to warrant further cycles. The recovered viscous material can be moved to the surface, by means well-known in the art, for further processing.

25 The above-mentioned injection/production cycle is one of several methods for recovering heavy hydrocarbons from underground formations. In this invention, two recovery mechanisms are described and used.

One mechanism involves a stimulation process, such as by steam. This process involves a single well and is well-

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known in the art as "huff and puff," since steam is injected into a reservoir optionally remaining for a finite soaking period, and then allowed to vent back through the entrance. Hydrocarbon production through the entrance is
5 then noted. Several stimulation cycles may be needed for an appreciable outflow of desired material. The injection well and the production well are the same well, depending on the time during the stimulation process.

The other mechanism is called a "drive," and at least
10 two wells are used. Here, for example, steam can be injected into one well, and, after a finite time, production is noted from a production well.

Pressure cycling, with variations in the steam pressure, can be used for either mechanism.

15 In another embodiment, steam, at a pressure above the fracture pressure of the formation to be exploited, is injected into the boreholes, as in the above-described embodiment, continuing the injection/production cycles until the viscous material between the wells is made
20 mobile, stopping the steam flow into the injector wells, completing selected second boreholes as producer wells, initiating a flooding procedure, exemplified by a fire flood, water flood, steam flood, emulsion flood, or solvent flood, flowing from injector wells to production wells, and
25 collecting the liberated material of reduced viscosity as before.

In another embodiment, after the second boreholes are extended substantially upward and radially outward into the desired formation from the operating chamber, some of these
30 second boreholes are completed as injector wells, and the

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remainder of the second boreholes are completed as producer wells. Then steam, at or above fracturing pressure, is injected into the second boreholes completed as injector wells. A number of injection/production cycles are carried
5 out so as to increase the temperature of that portion of the formation surrounding the boreholes. The steam flow into the boreholes designated as injector wells is then stopped, and a flooding procedure is initiated, using the same or a different procedure from the choices noted above,
10 such that the flooding material flows from injector wells to producer wells. The liberated material of reduced viscosity is then collected as before.

In a further embodiment of the invention, steam, at a pressure above fracturing pressure of the desired formation, is injected into the second boreholes as the begin-
15 ning of a stimulation phase. The injection/production cycles of steam stimulation are continued for some time so as to increase the temperature of the surrounding formation.

20 Selected second boreholes are completed as producer wells, and a steam flood is then initiated, with the variation that the steam pressure is cyclically varied. Following steps in the procedure are as previously described.

25 In another embodiment, after the second boreholes are drilled from the chamber into the desired formation, some of these second boreholes are completed as injector wells and the remainder are completed as producer wells. Then steam, at a pressure above the fracturing pressure, is
30 injected into the boreholes comprising the injector wells.

The previously described injection/production cycles are carried out, resulting in a temperature increase of the surrounding formation. A steam flood is then initiated, with the modification that the steam pressure is cyclically varied. Liberated hydrocarbon material is then treated as discussed above.

The embodiments discussed above have one or more of the advantages discussed below.

A central shaft, with associated radial boreholes, has the advantages over wells drilled from the surface of:

- (a) reduced drilling costs,
- (b) horizontal wells or boreholes are easier to drill,
- (c) there is less heat loss between the surface and the tar sands or oil sands, formation, or reservoir, and
- (d) the movement of recovered oil from the formation to the surface is more efficient than when wells are drilled from the surface.

The advantages of continuing the shaft or borehole into the zone below the formation or reservoir include:

- (a) increased safety, since an operating chamber is formed in the zone below the formation,
- (b) wells can be cemented in the zone below the formation, while there is great difficulty in cementing wells in an oil sands or tar sands formation, and
- (c) it is easier and safer to complete wells that have their beginning or terminus in the operating chamber below the formation.

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Using a steam pressure greater than the fracturing pressure of the formation allows injection of the steam into the formation or reservoir at a sufficient rate to recover the hydrocarbon product economically. The greater pressure also allows a higher percentage of the formation or reservoir to be contacted, and this gives a higher usage efficiency for the injected steam. This greater pressure also allows a greater percentage of the formation to be processed.

5
10 Cyclical operation involving varying the steam pressure improves the recovery of the product and offers an improved oil/steam ratio. The steam pressure can be varied from about atmospheric pressure to the operating pressure.

Other advantages of the embodiments of the process will be noted by those who are skilled in the arts involved in this process.

DESCRIPTION OF THE DRAWINGS

The Figure shows a side view of the borehole, the subsurface formations, the chamber in the formation below the hydrocarbon-containing formation, and the secondary boreholes extending from the chamber into the hydrocarbon-containing formation.

DETAILED DESCRIPTION OF THE INVENTION

25 The described process for the in situ recovery of viscous materials can be used where the desired formation or reservoir is greater than about 30 meters from the surface. For example, the invention is operable where the

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formation or reservoir is from about 90 to about 900 m. below the surface.

The thickness of the subsurface formation can vary, such as from about 1 m. to about 300 m, depending on the geology at that location. Formations thicker than about 5 m. are more economical to work.

In order to reduce the viscosity of, for example, the tar sands or oil sands found in the formation, an operating temperature of about 40°C or higher is desirable. The temperature of saturated steam at the injection pressure in the formation will give a gradient of operating temperatures, being highest near the injection nozzle and becoming lower as the distance from the injection nozzle increases.

The quality of the steam used for injection can vary from about 50% to about 100%. The injection pressure used should be of the order of about 17 kPa/m or more, preferably from about 22 to about 44 kPa per meter of depth. The steam injection rate should be about the water equivalent of 15 m³/day/well or more, preferably from about 80 to about 350 m³/day/well.

The number of vertical shafts penetrating the overburden, and the material underlying the formation will depend on the size of the deposit and the desired production rate. The minimum number is 1, while a preferred or working number can vary between about 4 and about 25.

The drawing illustrates a simplified cross-section view of an in situ operation. A shaft, or first borehole 2, is sunk through overburden 1 into the desired formation 3. The borehole is continued into the underlying stratum 4 below the desired formation 3, and chamber 5 is

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an optional structure at the base of the first borehole 2. From chamber 5, second boreholes 6 are drilled upwardly and radially outwardly, to penetrate formation 3. Casing 7 is used to reduce the probability of collapse of borehole 6
5 while in stratum 4. One embodiment of production tubing (borehole 6 completed as a producing well) is shown as 8. Some known method of moving material liberated from the borehole to the surface, such as a pump, is not shown.

The stimulation injection time should be 5 days or
10 more, such as from about 10 to about 100 days. The stimulation cycles are 1 or more, such as from about 5 to about 25.

The number of second boreholes extending upwardly and radially outwardly from the lower formation into the
15 hydrocarbon-bearing formation can vary from about 2 to about 40, preferably from about 2 to about 20. The radial length of these second boreholes can vary from a few meters, such as about 10, to a length that will allow connection with another, distant well, after the tempera-
20 ture of the intervening formation has been raised to allow movement of the desired material, such as a viscous hydrocarbon. This latter distance may vary from about 50 m. to about 600 m.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined below.

CLAIMS

1. A method for the in-situ recovery of viscous
5 materials from a subsurface formation, comprising:
- a) forming a first borehole to the base of the subsurface formation to be exploited,
 - b) extending the borehole below the base of the formation,
 - 10 c) drilling a plurality of second boreholes extending substantially upwardly and radially outwardly into said formation from the lower portion of the borehole of step (b),
 - d) injecting steam into said second boreholes,
15 with the steam having a pressure above the fracture pressure of the subsurface formation,
 - e) maintaining the injection of step (d) for a time period so as to increase the temperature of that portion of the formation
20 surrounding said second boreholes and any fracture fissures formed by the injection,
 - f) releasing the pressure on the system of second boreholes, thus allowing any liberated material of reduced viscosity to move
25 to the lower portions of said second boreholes and thence to the lower portion of the first borehole,

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- g) collecting the liberated material, and
- h) repeating the injection/production cycle of steps d-g.

2. The method of Claim 1 wherein

- 5 a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- b) the lower portion of the borehole is enlarged to form an operating chamber below
10 the base of the formation,
- c) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam in-
15 jection rate at a water equivalent of greater than $15 \text{ m}^3/\text{day}/\text{well}$,
- d) the plurality of second boreholes varies from about 2 to about 40,
- e) the injection time period of step (d) is at
20 least 5 days, and
- f) the repeated injection/production cycles of step (h) number at least two.

3. The method of claim 2, wherein

- 25 a) the number of second boreholes varies from about 2 to about 20,
- b) the steam injection rate has a water equivalent of from about 80 to about $350 \text{ m}^3/\text{day}/\text{well}$,

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- c) the injection time period can vary from about 10 to about 100 days, and
- d) the repeated injection/production cycles can number from about 2 to about 25.

- 5 4. A method for the in-situ recovery of viscous materials from a subsurface formation, comprising
- a) forming a first borehole to the base of the subsurface formation to be exploited,
 - 10 b) extending the borehole below the base of the formation,
 - c) drilling a plurality of second boreholes extending substantially upwardly and radially outwardly into said formation from the lower position of the borehole of step (b),
 - 15 d) injecting steam into said second boreholes, with the steam having a pressure above the fracture pressure of the subsurface formation,
 - 20 e) maintaining the injection of step (d) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
 - 25 f) releasing the pressure on the system of boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the second boreholes and thence to the lower portion of the first borehole,

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- g) collecting the liberated material,
 - h) repeating the injection/production cycle until the viscous material between at least some of the second boreholes is made mobile,
 - 5 i) stopping the steam flow into the second boreholes,
 - j) completing selected second boreholes as producer wells,
 - 10 k) initiating a flooding procedure, selected from the procedures consisting of fire flood, water flood, steam flood, emulsion flood, and solvent flood, flowing from at least one injector well to at least one producing well, and
 - 15 l) collecting the liberated material.
5. The method of claim 4, wherein
- a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
 - 20 b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
 - c) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam in-
 - 25 jection rate at a water equivalent of greater than 15 m³/day/well.

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- d) the plurality of second boreholes varies from about 2 to about 40,
 - e) the injection time period of step (d) is at least 5 days, and
 - 5 f) the repeated injection/production cycles of step (h) number at least two.
6. The method of claim 5, wherein
- a) the number of second boreholes varies from about 2 to about 20,
 - 10 b) the steam injection rate has a water equivalent of from about 80 to about 350 m³/day/well,
 - c) the injection time period can vary from about 10 to about 100 days, and
 - 15 d) the repeated injection/production cycles can number from about 2 to about 25.
7. A method for the in-situ recovery of viscous materials from a subsurface formation, comprising
- 20 a) forming a first borehole to the base of the subsurface formation to be exploited,
 - b) extending the borehole below the base of the formation,
 - c) drilling a plurality of second boreholes extending substantially upwardly and radially outwardly into said formation from the lower portion of the first borehole of step (b),
 - 25 d) completing at least one of said second boreholes as an injector well, while completing

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the remainder of said second boreholes as producer wells,

- e) injecting steam into said second boreholes completed as injector wells, with the pressure of the steam above the fracture pressure of the subsurface formation,
- f) maintaining the injection of step (e) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- g) releasing the pressure on the system of injector boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the first borehole,
- h) repeating the injection/production cycle of steps (e) - (g) until hydrocarbon between at least some of said second boreholes is mobilized,
- i) stopping the steam flow to the injector well and collecting the liberated material,
- j) initiating a flood procedure, selected from the procedures consisting of fire flood, water flood, steam flood, emulsion flood, solvent flood, flowing from an injector well to a producer well, and
- k) collecting the liberated material.

8. The method of claim 7, wherein

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- 5
- a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
- 10
- c) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam injection rate at a water equivalent of greater than 15 m³/day/well,
- d) the plurality of second boreholes varies from about 2 to about 40,
- 15
- e) the injection time period of step (d) is at least 5 days, and
- f) the repeated injection/production cycles of step (h) number at least two.
9. The method of claim 8, wherein
- 20
- a) the number of second boreholes varies from about 2 to about 20,
- b) the steam injection rate has a water equivalent of from about 80 to about 350 m³/day/well,
- 25
- c) the injection time period can vary from about 10 to about 100 days, and
- d) the repeated injection/production cycles can number from about 2 to about 25.

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10. A method for the in-situ recovery of viscous materials from a subsurface formation, comprising

- a) forming a first borehole to the base of the subsurface formation to be exploited,
- 5 b) extending the borehole below the base of the formation,
- c) drilling a plurality of second boreholes extending substantially upwardly and radially outwardly into said formation from the lower portion of the borehole of step (b),
- 10 d) injecting steam into said second boreholes, with the steam having a pressure above the fracture pressure of the subsurface formation,
- 15 e) maintaining the injection of step (d) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 20 f) releasing the pressure on the system of second boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of said second boreholes and thence to the lower portion of the first borehole.
- 25 g) collecting the liberated material,
- h) repeating the injection/production cycle until the viscous material between at least some of the second boreholes is mobilized,

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- i) stopping the steam flow,
 - j) completing selected second boreholes as producer wells,
 - k) initiating a steam flooding procedure,
 - 5 l) cyclically varying the steam pressure during the operation of step (k), and
 - m) collecting the liberated material.
11. The method of claim 10, wherein
- 10 a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
 - b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
 - 15 c) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam injection rate at a water equivalent of
 - 20 greater than $15 \text{ m}^3/\text{day}/\text{well}$,
 - d) the plurality of second boreholes varies from about 2 to about 40,
 - e) the injection time period of step (d) is at least 5 days,
 - 25 f) the repeated injection/production cycles of step (h) number at least two, and
 - g) the steam pressure of step (e) varies from about atmospheric to the operating pressure.

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12. The method of claim 11, wherein

- a) the number of second boreholes varies from about 2 to about 20,
- b) the steam injection rate has a water equivalent of from about 80 to about 350 m³/day/well,
- c) the injection time period can vary from about 10 to about 100 days, and
- d) the repeated injection/production cycles can number from about 2 to about 25.

13. A method for the in-situ recovery of viscous materials from a subsurface formation, comprising

- a) forming a first borehole to the base of the subsurface formation to be exploited,
- b) extending the borehole below the base of the formation,
- c) drilling a plurality of second boreholes extending substantially upwardly and radially outwardly into said formation from the lower portion of the borehole of step (b),
- d) completing at least one of said second boreholes as an injector well, while completing the remainder of said second boreholes as producer wells,
- e) injecting steam into said second boreholes designated injector wells, with the steam having a pressure above the fracture pressure of the subsurface formation,

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- 5
- f) maintaining the injection of Step (e) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- g) releasing the pressure on the boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the first borehole,
- 10 h) repeating the injection/production cycle until hydrocarbon between at least some of said second boreholes is mobilized,
- i) initiating a steam flooding procedure, and
- 15 j) cyclically varying the steam pressure during the operation of step (i), and
- k) collecting the liberated material.
14. The method of claim 13, wherein
- a) the subsurface formation containing viscous materials is approximately 30 meters or more
- 20 below the surface,
- b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
- c) the injection stream has a steam quality of
- 25 from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam injection rate at a water equivalent of greater than 15 m³/day/well,

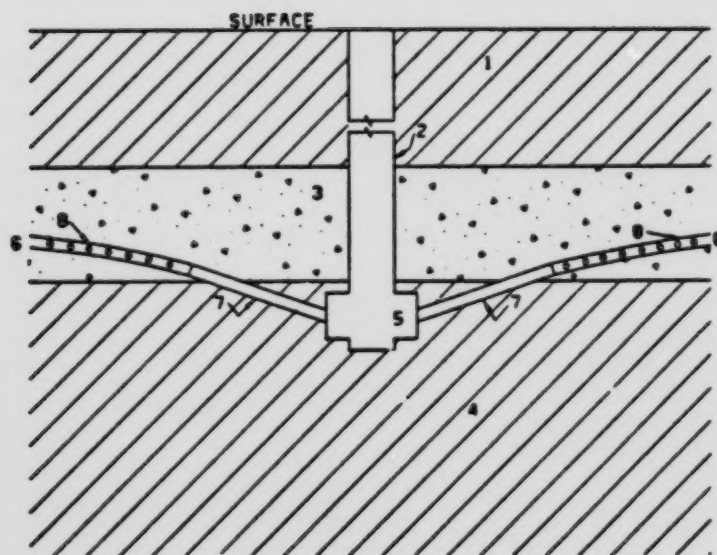
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- d) the plurality of second boreholes varies from about 2 to about 40,
 - e) the injection time period of step (d) is at least 5 days,
 - 5 f) the repeated injection/production cycles of step (h) number at least two, and
 - g) the steam pressure of step (j) varies from about atmospheric to the operating pressure.
15. The method of claim 14, wherein
- 10 a) the number of second boreholes varies from about 2 to about 20,
 - b) the steam injection rate has a water equivalent of from about 80 to about 300 m³/day/well,
 - 15 c) the injection time period can vary from about 10 to about 100 days, and
 - d) the repeated injection/production cycles can number from about 2 to about 25.

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(54) In Situ Recovery of Viscous Materials

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BACKGROUND OF THE INVENTION

This invention relates to a method for the recovery of materials such as minerals and viscous hydrocarbons from subsurface earth formations. In a particular application
5 of the invention, the method relates to the in situ recovery of bitumen from tar sands or oil sands.

Various techniques have been considered for recovering bitumen from tar sand formations that are too deep for surface mining. These techniques typically involve raising
10 the temperature of the formation to reduce the viscosity of the bitumen, to assist in the separation of the bitumen from the sand matrix, and to promote movement of the liberated bitumen. The temperature can be raised by various means, such as electrical heating, fire flooding,
15 steam flooding, etc. Due to the high expenses and low recovery rates, these techniques typically have not been too successful.

There are also various types of mining techniques frequently used in the prior art to reach and process these
20 deep tar sands. Some of the techniques used involve drilling or excavating one or more vertical shafts into the tar sand formation and then extending lateral horizontal tunnels from the shaft. U.S. 4,160,481 discusses some of these techniques.

25 The inherent and expressed disadvantages of the prior art are overcome with the present invention.

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SUMMARY OF THE INVENTION

There are several embodiments involved in the present invention, and these generally involve different methods of entering and then thermally treating the tar sand formation.

- 5 All of the embodiments involve a first step of drilling or excavating a borehole or shaft to the base of the subsurface formation to be exploited. Typically this formation is a tar sands or oil sands formation, but the technique can be used in other subsurface formations that comprise
10 solid and semi-solid and viscous materials such as kerogen, high viscosity hydrocarbon materials such as heavy oils, inorganic ores, and the like.

- The terminal end of the shaft or borehole, at the base of the desired formation, is then, optionally, enlarged to
15 form an operating chamber at the base of the desired formation.

The next step concerns the drilling of a plurality of second boreholes extending substantially radially outward into the desired formation from this operating chamber.

- 20 The above-listed steps are common to the first phase of the invention. Various embodiments of the invention are practiced by altering the succeeding steps.

- For example, in one embodiment, steam is conducted down the first borehole or shaft and thence injected into
25 the plurality of second boreholes drilled from the operating chamber. Or steam can be generated in the chamber and then injected into the plurality of boreholes. It is a feature of this embodiment that the steam used is at a pressure above the fracture pressure of the formation to be
30 exploited. It is a characteristic of oil sands or similar

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hydrocarbon deposits that any flow channels in the formation matrix are effectively plugged with the solid or semi-solid hydrocarbon material. The rate of injection for steam or any other heating medium at subfracture pressures would be too low to achieve the rate of heat input necessary to recover economically the hydrocarbon. Steam pressures above fracture pressure will permit high rates of injection. The injection of this steam is maintained for a time period resulting in an increase of the temperature of that portion of the formation surrounding the boreholes and the chamber. A "soaking" cycle can follow, for a discrete time period. When the pressure of the steam on the system is released, any liberated material of reduced viscosity can move, by gravity, and by means of the increased pressure due to the steam injection, to the lower portions of the second boreholes and thence to the lower portion of the chamber found at the base of the desired formation. The injection/production cycle is repeated until insufficient additional hydrocarbon is produced to warrant further cycles. The recovered viscous material can be moved to the surface, by means well-known in the art, for further processing.

The above-mentioned injection/production cycle is one of several methods for recovering heavy hydrocarbons from underground formations. In this invention, two recovery mechanisms are described and used.

One mechanism involves a stimulation process, such as by steam. This process involves a single well and is well-known in the art as "huff and puff," since steam is injected into a reservoir, optionally remaining for a

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finite soaking period, and then allowed to vent back through the entrance. Hydrocarbon production through the entrance is then noted. Several stimulation cycles may be needed for an appreciable outflow of desired material. The
5 injection well and the production well are the same well, depending on the time during the stimulation process.

The other mechanism is called a "drive," and at least two wells are used. Here, for example, steam can be injected into one well, and, after a finite time, produc-
10 tion is noted from a production well.

Pressure cycling, with variations in the steam pressure, can be used for either mechanism.

In another embodiment of the present invention, steam, at a pressure above the fracture pressure of the
15 formation to be exploited, is injected into the boreholes, as in the above-described embodiment, the injection/production cycles are continued until the viscous material between the wells is made mobile, the steam flow into the injector wells is stopped, selected second boreholes are
20 completed as producer wells, a flooding procedure is initiated, exemplified by a fire flood, water flood, steam flood, emulsion flood, or solvent flood, flowing from injector wells to production wells, and the liberated material of reduced viscosity is collected, as before.

25 In another embodiment, after the second boreholes are extended radially outward into the desired formation from the operating chamber, some of these second boreholes are completed as injector wells, and the remainder of the second boreholes are completed as producer wells. Then
30 steam, at or above fracturing pressure, is injected into

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the second boreholes completed as injector wells. A number of injection/production cycles are carried out so as to increase the temperature of that portion of the formation surrounding the boreholes. The steam flow into the bore-
5 holes designated as injector wells is then stopped, and a flooding procedure is initiated, using the same or a different procedure from the choices noted above, such that the flooding material flows from injector wells to producer wells. The liberated material of reduced viscosity is then
10 collected as before.

In a further embodiment of the invention, steam, at a pressure above fracturing pressure of the desired formation, is injected into the second boreholes as the beginning of a stimulation phase. The injection/production
15 cycles of steam stimulation are continued for some time so as to increase the temperature of the surrounding formation.

Selected second boreholes are completed as producer wells, and a steam flood is then initiated, with the variation that the steam pressure is cyclically varied. Following steps in the procedure are as previously described.
20

In another embodiment, after the second boreholes are drilled from the terminal end of the shaft, or the chamber, into the desired formation, some of these second boreholes
25 are completed as injector wells and the remainder are completed as producer wells. Then steam, at a pressure above the fracturing pressure, is injected into the boreholes comprising the injector wells. The previously described injection/production cycles are carried out,
30 resulting in a temperature increase of the surrounding

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formation. A steam flood is then initiated, with the modification that the steam pressure during the flooding is cyclically varied. The steam pressure can be varied from about atmospheric pressure to the operating pressure.

- 5 Liberated hydrocarbon material is then treated as discussed above.

The embodiments discussed above have one or more of the advantages discussed below.

- 10 A central shaft, with associated radial boreholes, has the advantages over wells drilled from the surface of:

- (a) reduced drilling costs,
- (b) horizontal wells or boreholes are easier to drill,
- 15 (c) there is less heat loss between the surface and the tar sands or oil sands, formation, or reservoir, and
- (d) the movement of recovered oil from the formation to the surface is more efficient than when wells are drilled from the surface.

- 20 Using a steam pressure greater than the fracturing pressure of the formation allows injection of the steam into the formation or reservoir at a sufficient rate to recover the hydrocarbon product economically. The greater pressure also allows a higher percentage of the formation
- 25 or reservoir to be contacted, and this gives a higher usage efficiency for the injected steam. This greater pressure also allows a greater percentage of the formation to be processed.

- 30 Cyclical operation involving varying the steam pressure improves the recovery of the product and offers an

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improved oil/steam ratio. The cycle time, from peak to peak, can vary from about 10 to about 50 hours.

Other advantages of the embodiments of the process will be noted by those who are skilled in the arts involved
5 in this process.

DESCRIPTION OF THE DRAWINGS

The Figure shows a side view of the borehole, the subsurface formations, the chamber in the formation below the hydrocarbon-containing formation, and the secondary
10 boreholes extending from the chamber into the hydrocarbon-containing formation.

DETAILED DESCRIPTION OF THE INVENTION

The described process for the in situ recovery of viscous materials can be used where the desired formation
15 or reservoir is greater than about 20 meters from the surface. For example, the invention is operable where the formation or reservoir is from about 90 to about 900 meters below the surface.

The thickness of the subsurface formation can vary,
20 such as from about 1 m. to about 300 m., depending on the geology at that location. Formations thicker than about 5 m. are more economical to work.

In order to reduce the viscosity of, for example, the tar sands or oil sands found in the formation an operating temperature of about 40°C or higher is desirable.
25 The temperature of saturated steam at the injection pressure in the formation will give a gradient of operating temperatures, being highest near the injection nozzle and

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becoming lower as the distance from the injection nozzle increases.

The quality of the steam used for injection can vary from about 50% to about 100%. The injection pressure used
5 should be of the order of about 17 kPa/m or more, preferably from about 22 to about 44 kPa per meter of depth. The steam injection rate should be about the water equivalent of 15 m³/d/well or more, preferably from about 80 to about 350 m³/d/well.

10 The number of vertical shafts penetrating the overburden, and the material underlying the formation will depend on the size of the deposit and the desired production rate. The minimum number is 1, while a preferred or working number can vary between about 4 and about 25.

15 The drawing illustrates a simplified cross-section view of an in situ operation. A shaft, or first borehole 2, is sunk through overburden 1 into the desired formation 3. The borehole is continued to the top of the underlying stratum 4 below the desired formation 3, and
20 chamber 5 is an optional structure at the base of the first borehole 2. From chamber 5, second boreholes 6 are drilled radially outwardly, to penetrate formation 3. Casing 7 is used to reduce the probability of collapse of borehole 6 while in formation 3. One embodiment of production tubing
25 (borehole 6 completed as a producing well) is shown as 8. Some known method of moving material liberated from the borehole to the surface, such as a pump, is not shown.

The stimulation injection time should be 5 days or more, such as from about 10 to about 100 days. The number

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of stimulation cycles are 1 or more, such as from about 5 to about 25.

The number of second boreholes extending radially outwardly from the lower formation into the hydrocarbon-bearing formation can vary from about 2 to about 40, preferably from about 2 to about 20. The radial length of these second boreholes can vary from a few meters, such as about 30 to a length that will allow connection with another, distant well, after the temperature of the intervening formation has been raised to allow movement of the desired material, such as a viscous hydrocarbon. This latter distance may vary from about 50 m. to about 600 m.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined below.

CLAIMS

1. A method for the in-situ recovery of viscous
5 materials from a subsurface formation, comprising:
- a) forming a first borehole to the base of the subsurface formation to be exploited,
 - b) drilling a plurality of second boreholes extending substantially radially outwardly
10 into said formation,
 - c) injecting steam into said second boreholes, with the steam having a pressure above the fracture pressure of the subsurface formation,
 - 15 d) maintaining the injection of step (c) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
 - 20 e) releasing the pressure on the system of second boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portions of said second boreholes and thence to the lower portion of the
25 first borehole,
 - f) collecting the liberated material, and

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- g) repeating the injection/production cycle of steps c-f.

2. The method of claim 1 wherein

- 5 a) the subsurface formation containing viscous materials is approximately 100 ft. (30 m.) or more below the surface,
- b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
- 10 c) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam injection rate at a water equivalent of
- 15 greater than $15 \text{ m}^3/\text{d}/\text{well}$,
- d) the plurality of second boreholes varies from about 2 to about 40,
- e) the injection time period of step (d) is at least 5 days, and
- 20 f) the repeated injection/production cycles of step (g) number at least two.

3. The method of claim 2, wherein

- a) the number of second boreholes varies from about 2 to about 20,
- 25 b) the steam injection rate has a water equivalent of from about 80 to about $350 \text{ m}^3/\text{d}/\text{well}$,

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- c) the injection time period can vary from about 10 to about 100 days, and
- d) the repeated injection/production cycles can number from about 2 to about 25.

5 4. A method for the in situ recovery of viscous materials from a subsurface formation, comprising

- a) forming a first borehole to the base of the subsurface formation to be exploited,
- 10 b) drilling a plurality of second boreholes extending radially outwardly into said formation from the lower portion of the first borehole,
- 15 c) injecting steam into said second boreholes, with the steam having a pressure above the fracture pressure of the subsurface formation,
- 20 d) maintaining the injection of step (c) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 25 e) releasing the pressure on the system of boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the second boreholes and thence to the lower portion of the first borehole,
- f) collecting the liberated material.

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- 5 g) repeating the injection/production cycle until the viscous material between at least some of the second boreholes is made mobile,
- h) stopping the steam flow into the second boreholes,
- 10 i) completing selected second boreholes as producer wells,
- j) initiating a flooding procedure, selected from the procedures consisting of fire flood, water flood, steam flood, emulsion flood, and solvent flood, flowing from at least one injector well to at least one producing well, and
- k) collecting the liberated material.
- 15 5. The method of claim 4, wherein
- a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- 20 b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
- 25 c) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam injection rate at a water equivalent of greater than $15 \text{ m}^3/\text{d}/\text{well}$,

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- d) the plurality of second boreholes varies from about 2 to about 40,
 - e) the injection time period of step (d) is at least 5 days, and
 - 5 f) the repeated injection/production cycles of step (g) number at least two.
6. The method of claim 5, wherein
- a) the number of second boreholes varies from about 2 to about 20,
 - 10 b) the steam injection rate has a water equivalent of from about 80 to about 350 m³/d/well
 - c) the injection time period can vary from about 10 to about 100 days, and
 - 15 d) the repeated injection/production cycles can number from about 2 to about 25.
7. A method for the in situ recovery of viscous materials from a subsurface formation, comprising
- a) forming a first borehole to the base of the subsurface formation to be exploited,
 - 20 b) drilling a plurality of second boreholes extending radially outwardly into said formation from the lower portion of the first borehole,
 - c) completing at least one of said second boreholes as an injector well, while completing the remainder of said second boreholes as producer wells,
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- d) injecting steam into said second boreholes completed as injector wells, with the pressure of the steam above the fracture pressure of the subsurface formation,
- 5 e) maintaining the injection of Step (d) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 10 f) releasing the pressure on the system of injector boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the first borehole,
- 15 g) repeating the injection/production cycle of steps (d) - (f) until the viscous material between at least some of said second boreholes is mobilized,
- h) stopping the steam flow to the injector well and collecting the liberated material,
- 20 i) initiating a flood procedure, selected from the procedures consisting of fire flood, water flood, steam flood, emulsion flood, solvent flood, flowing from an injector well to a producer well, and
- 25 j) collecting the liberated material.

8. The method of claim 7, wherein

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- 5 a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
- 10 c) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam injection rate at a water equivalent of greater than $15 \text{ m}^3/\text{d}/\text{well}$,
- d) the plurality of second boreholes varies from about 2 to about 40,
- 15 e) the injection time period of step (d) is at least 5 days, and
- f) the repeated injection/production cycles of step (h) number at least two.
9. The method of claim 8, wherein
- 20 a) the number of second boreholes varies from about 2 to about 20,
- b) the steam injection rate has a water equivalent of from about 80 to about $350 \text{ m}^3/\text{d}/\text{well}$,
- 25 c) the injection time period can vary from about 10 to about 100 days, and
- d) the repeated injection/production cycles can number from about 2 to about 25.

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10. A method for the in situ recovery of viscous materials from a subsurface formation, comprising

- a) forming a first borehole to the base of the subsurface formation to be exploited,
- 5 b) drilling a plurality of second boreholes extending radially outwardly into said formation from the lower portion of the first borehole,
- 10 c) injecting steam into said second boreholes, with the steam having a pressure above the fracture pressure of the subsurface formation,
- 15 d) maintaining the injection of step (c) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 20 e) releasing the pressure on the system of second boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of said second boreholes and thence to the lower portion of the first borehole,
- 25 f) collecting the liberated material,
- g) repeating the injection/production cycle until the viscous material between at least some of the second boreholes is mobilized,
- h) stopping the steam flow,
- 30 i) completing selected second boreholes as producer wells,

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- j) initiating a steam flooding procedure,
- k) cyclically varying the steam pressure during the operation of step (j), and
- l) collecting the liberated material.

5 11. The method of claim 10, wherein

- a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
- c) the injection stream has a steam quality of from about 17 kPa to about 44 kPa, per meter of depth from the surface, and a steam injection rate at a water equivalent of greater than 15 m³/d/well,
- d) the plurality of second boreholes varies from about 2 to about 40,
- e) the injection time period of step (d) is at least 5 days,
- f) the repeated injection/production cycles of step (h) number at least two, and
- g) the steam pressure of step (k) varies from about atmospheric to the operating pressure.

25 12. The method of claim 11, wherein

- a) the number of second boreholes varies from about 2 to about 20,

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- 5 b) the steam injection rate has a water equivalent of from about 80 to about 350 m³/d/well,
- c) the injection time period can vary from about 10 to about 100 days, and
- d) the repeated injection/production cycles can number from about 2 to about 25.
13. A method for the in situ recovery of viscous materials from a subsurface formation, comprising
- 10 a) forming a first borehole to the base of the subsurface formation to be exploited,
- b) drilling a plurality of second boreholes extending radially outwardly into said formation from the lower portion of the
- 15 first borehole,
- c) completing at least one of said second boreholes as an injector well, while completing the remainder of said second boreholes as producer wells,
- 20 d) injecting steam into said second boreholes designated injector wells, with the steam having a pressure above the fracture pressure of the subsurface formation,
- 25 e) maintaining the injection of Step (d) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,

- (
- f) releasing the pressure on the boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the first borehole,
 - 5 g) repeating the injection/production cycle until hydrocarbon between at least some of said second boreholes is mobilized,
 - h) initiating a steam flooding procedure, and
 - 10 i) cyclically varying the steam pressure during the operation of step (h), and
 - j) collecting the liberated material.

14. The method of claim 13, wherein

- 15 a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- b) the lower portion of the borehole is enlarged to form an operating chamber below the base of the formation,
- 20 c) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam injection rate at a water equivalent of greater than 15 m³/d/well,
- 25 d) the plurality of second boreholes varies from about 2 to about 40,
- e) the injection time period of step (d) is at least 5 days.

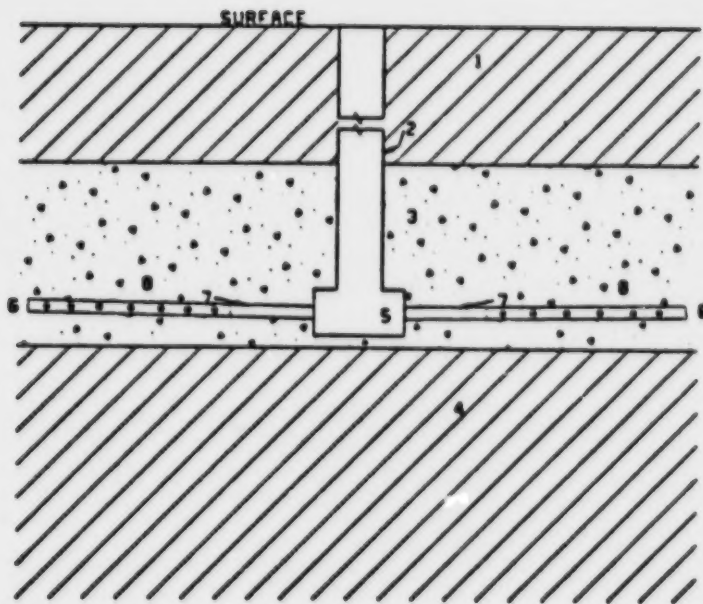
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- f) the repeated injection/production cycles of step (g) number at least two, and
- g) the steam pressure of step (i) varies from about atmospheric to the operating pressure.

- 5 15. The method of claim 14, wherein
- a) the number of second boreholes varies from about 2 to about 20,
 - b) the steam injection rate has a water equivalent of from about 80 to about 350 m³/d/well,
 - 10 c) the injection time period can vary from about 10 to 100 days, and
 - d) the repeated injection/production cycles can number from about 2 to about 25.

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(54) In Situ Recovery of Viscous Materials

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BACKGROUND OF THE INVENTION

This invention relates to a method for the recovery of materials such as minerals and viscous hydrocarbons from subsurface earth formations. In a particular application
5 of the invention, the method relates to the in situ recovery of bitumen from tar sands or oil sands.

Various techniques have been considered for recovering bitumen from tar sand formations that are too deep for surface mining. These techniques typically involve raising
10 the temperature of the formation to reduce the viscosity of the bitumen, to assist in the separation of the bitumen from the sand matrix, and to promote movement of the liberated bitumen. The temperature can be raised by various means, such as electrical heating, fire flooding,
15 steam flooding, etc. Due to the high expenses and low recovery rates, these techniques typically have not been too successful.

There are also various types of mining techniques frequently used in the prior art to reach and process these
20 deep tar sands. Some of the techniques used involve drilling or excavating one or more vertical shafts into the tar sand formation and then extending lateral horizontal tunnels from the shaft. U.S. 4,160,481 discusses some of these techniques.

25 The inherent and expressed disadvantages of the prior art are overcome with the present invention.

SUMMARY OF THE INVENTION

There are several embodiments involved in the present invention, and these generally involve different methods of

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entering and then thermally treating the tar sand formation. All of the embodiments involve a first step of drilling or excavating a borehole or shaft to the base of the subsurface formation to be exploited. Typically
5 this formation is a tar sands or oil sands formation, but the technique can be used in other subsurface formations that comprise solid and semisolid and viscous materials such as kerogen, high viscosity hydrocarbon materials such as heavy oils, inorganic ores, and the like.

10 The terminal end of the shaft or borehole, is then, optionally, enlarged to form an operating chamber at the base of the desired formation. The next step involves the excavating of one or more tunnels extending laterally from this operating chamber, at the base of the formation.

15 The next step concerns the drilling of a plurality of second boreholes extending substantially outwardly into the desired formation from the tunnels.

The above-listed steps are common to the first phase of the invention. Various embodiments of the invention are
20 practiced by altering the succeeding steps.

For example, in one embodiment, steam is conducted down the first borehole or shaft, along the tunnels, and thence injected into the plurality of second boreholes drilled from the tunnels. Or steam can be generated in
25 the chamber and then injected into the plurality of boreholes. It is a feature of this embodiment that the steam used is at a pressure above the fracture pressure of the formation to be exploited. It is a characteristic of oil sands or similar hydrocarbon deposits that any flow channels
30 in the formation matrix are effectively plugged with the solid

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or semisolid hydrocarbon material. The rate of injection for steam or any other heating medium at subfracture pressures would be too low to achieve the rate of heat input necessary to recover economically the hydrocarbon. Steam
5 pressures above fracture pressure will permit high rates of injection. The injection of this steam is maintained for a time period resulting in an increase of the temperature of that portion of the formation surrounding the boreholes and the chamber. A "soaking" cycle can follow, for a discrete
10 time period. When the pressure of the steam on the system is released, any liberated material of reduced viscosity can move, by gravity, and by means of the increased pressure due to the steam injection, to the lower portions of the second boreholes and thence to the lower portion of the
15 chamber found in the stratum below the desired formation. The injection/production cycle is repeated until insufficient additional hydrocarbon is produced to warrant further cycles. The recovered viscous material can be moved to the surface, by means well-known in the art, for further
20 processing.

The above-mentioned injection/production cycle is one of several methods for recovering heavy hydrocarbons from underground formations. In this invention, two recovery mechanisms are described and used.

25 One mechanism involves a stimulation process, such as by steam. This process involves a single well and is well-known in the art as "huff and puff," since steam is injected into a reservoir optionally remaining for a finite soaking period, and then allowed to vent back through the
30 entrance. Hydrocarbon production through the entrance is

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then noted. Several stimulation cycles may be needed for an appreciable outflow of desired material. The injection well and the production well are the same well, depending on the time during the stimulation process.

- 5 The other mechanism is called a "drive," and at least two wells are used. Here, for example, steam can be injected into one well, and, after a finite time, production is noted from a production well.

10 Pressure cycling, with variations in the steam pressure, can be used for either mechanism.

- 15 In another embodiment, steam, at a pressure above the fracture pressure of the formation to be exploited, is injected into the boreholes, as in the above-described embodiment, continuing the injection/ production cycles until the viscous material between the wells is made mobile, stopping the steam flow into the injector wells, completing selected second boreholes as producer wells, initiating a flooding procedure, exemplified by a fire flood, water flood, steam flood, emulsion flood, or solvent
20 flood, flowing from injector wells to production wells, and collecting the liberated material of reduced viscosity as before.

- 25 In another embodiment, after the second boreholes are extended substantially outward into the desired formation from the tunnels, some of these second boreholes are completed as injector wells, and the remainder of the second boreholes are completed as producer wells. Then steam, at or above fracturing pressure, is injected into the second boreholes completed as injector wells. A number of injection/production cycles are carried out so as to increase
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the temperature of that portion of the formation surrounding the boreholes. The steam flow into the boreholes designated as injector wells is then stopped, and a flooding procedure is initiated, using the same or a different
5 procedure from the choices noted above, such that the flooding material flows from injector wells to producer wells. The liberated material of reduced viscosity is then collected as before.

In a further embodiment of the invention, steam, at a
10 pressure above fracturing pressure of the desired formation, is injected into the second boreholes as the beginning of a stimulation phase. The injection/production cycles of steam stimulation are continued for some time so as to increase the temperature of the surrounding formation.

15 Selected second boreholes are completed as producer wells, and a steam flood is then initiated, with the variation that the steam pressure is cyclically varied. Following steps in the procedure are as previously described.

20 In another embodiment, after the second boreholes are drilled from the chamber into the desired formation, some of these second boreholes are completed as injector wells and the remainder are completed as producer wells. Then steam, at a pressure above the fracturing pressure, is
25 injected into the boreholes comprising the injector wells. The previously-described injection/production cycles are carried out, resulting in a temperature increase of the surrounding formation. A steam flood is then initiated, with the modification that the steam pressure is cyclically

varied. Liberated hydrocarbon material is then treated as discussed above.

The embodiments discussed above have one or more of the advantages discussed below.

5 A central shaft, with associated tunnels and boreholes, has the advantages over wells drilled from the surface of:

- (a) reduced drilling costs,
- (b) horizontal wells or boreholes are easier to drill,
- 10 (c) there is less heat loss between the surface and the tar sands or oil sands, formation, or reservoir, and
- (d) the movement of recovered oil from the formation to the surface is more efficient than
- 15 when wells are drilled from the surface.

The advantage of using tunnels from the shaft as the starting point for the boreholes, rather than drilling the borehole radially outward from the shaft, is that the boreholes can be drilled parallel to one another, giving a more
20 uniform coverage of the reservoir. The rectangular layout with tunnels is also more amenable to a repeated pattern.

Using a steam pressure greater than the fracturing pressure of the formation allows injection of the steam into the formation or reservoir at a sufficient rate to
25 recover the hydrocarbon product economically. The greater pressure also allows a higher percentage of the formation or reservoir to be contacted, and this gives a higher usage efficiency for the injected steam. This greater pressure also allows a greater percentage of the formation to be
30 processed.

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Cyclical operation involving varying the steam pressure improves the recovery of the product and offers an improved oil/steam ratio. The steam pressure during flooding can vary from about atmospheric to operating pressure.

- 5 The cycle time, from peak to peak, can vary from about 10 to about 50 hours.

Other advantages of the embodiments of the process will be noted by those who are skilled in the arts involved in this process.

10

DESCRIPTION OF THE DRAWINGS

Figure 1 is a side view of the borehole, the subsurface formations, the tunnel extending outwardly from the base of the borehole, and the secondary boreholes extending from the tunnel into the hydrocarbon-containing formation.

15

Figure 2 is a top view of the first borehole, the tunnel, and the secondary boreholes.

DETAILED DESCRIPTION OF THE INVENTION

- The described process for the in situ recovery of viscous materials can be used where the desired formation or reservoir is greater than about 30 meters from the surface. For example, the invention is operable where the formation or reservoir is from about 90 to about 900 meters below the surface.
- 20

- The thickness of the subsurface formation can vary, such as from about 1 m to about 300 m, depending on the geology at that location. Formations thicker than about 5 m are more economical to work.
- 25

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In order to reduce the viscosity of, for example, the tar sands or oil sands found in the formation an operating temperature of about 40°C or higher is desirable. The temperature of saturated steam at the injection pressure in the formation will give a gradient of operating temperatures, being highest near the injection nozzle and becoming lower as the distance from the injection nozzle increases.

The quality of the steam used for injection can vary from about 50% to about 100%. The injection pressure used should be of the order of about 17 kPa/m or more, preferably from about 22 to about 44 kPa per meter of depth. The steam injection rate should be about the water equivalent of 15 m³/d/well or more, preferably from about 80 to about 350 m³/d/well.

The number of vertical shafts penetrating the overburden, and the material underlying the formation will depend on the size of the deposit and the desired production rate. The minimum number is 1, while a preferred or working number can vary between about 4 and about 25.

The number of tunnels starting from each shaft can vary from 1 to 4, depending on the desired layout. The preferred number is 1 or 2. The length of each tunnel will normally be established by ventilation requirements.

Figure 1 illustrates a simplified cross-section view of an in situ operation. A shaft, or first borehole 2, is sunk through overburden 1 into the desired formation 3, ending at the upper portion of underlying stratum 4. Tunnel 5 extends laterally from the base of the first borehole 2. From tunnel 5, second boreholes 6 are drilled outwardly, through formation 3. Casing 7 is used to reduce

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the probability of collapse of borehole 6. One embodiment of production tubing (borehole 6 completed as a producing well) is shown as 8. Some known method of moving material liberated from the borehole to the surface, such as a pump, is not shown.

Figure 2 is a top view showing one version of the relationship of shaft 1, tunnel 2, and second boreholes 3.

The stimulation injection time should be 5 days or more, such as from about 10 to about 100 days. The stimulation cycles are 1 or more, such as from about 5 to about 25.

The number of second boreholes extending outwardly from the tunnels into the hydrocarbon-bearing formation can vary with the length of the tunnel, the number varying from 2 to about 20 for such tunnel, with spacing about 5 to 300 meters, preferably from about 5 to about 200 meters. The length of these second boreholes can vary from a few meters such as about 3, to a length that will allow connection with another, distant well, after the temperature of the intervening formation has been raised to allow movement of the desired material, such as a viscous hydrocarbon. This latter distance may vary from about 50 meters to about 600 meters.

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CLAIMS

1. A method for the in situ recovery of viscous materials from a subsurface formation, comprising:

- 5 a) forming a first borehole to the base of the subsurface formation to be exploited,
- b) extending one or more tunnels from the first borehole or shaft at the base of the formation,
- 10 c) drilling a plurality of second boreholes extending substantially outwardly into said formation from the tunnel(s) of step (b),
- d) injecting steam into said second boreholes, with the steam having a pressure above the fracture pressure of the subsurface formation,
- 15 e) maintaining the injection of step (d) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 20 f) releasing the pressure on the system of second boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portions of said second boreholes and thence to the lower portion of the
- 25 first borehole,
- g) collecting the liberated material, and
- h) repeating the injection/production cycle of steps (d)-(g).

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2. The method of Claim 1 wherein:

- a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- 5 b) the number of tunnels can vary from 1 to about 4,
- c) the spacing of the second boreholes varies from about 5 to about 300 meters,
- 10 d) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa, per meter of depth from the surface, and a steam injection rate at a water equivalent of greater than $15 \text{ m}^3/\text{d}/\text{well}$,
- 15 e) the lower portion of the borehole or shaft is enlarged to form an operating chamber at the base of the formation,
- f) the injection time period of step (d) is at least 5 days, and
- 20 g) the repeated injection/production cycles of step (h) number at least two.

3. The method of claim 2, wherein:

- a) the number of second boreholes varies from about 2 to about 20,
- 25 b) the steam injection rate has a water equivalent of from about 80 to about $350 \text{ m}^3/\text{d}/\text{well}$,
- c) the injection time period can vary from about 10 to about 100 days, and

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- d) the repeated injection/production cycles can number from about 2 to about 25.

4. A method for the in situ recovery of viscous materials from a subsurface formation, comprising:

- 5 a) forming a first borehole to the base of the subsurface formation to be exploited,
- b) extending one or more tunnels horizontally outward from the first borehole or shaft at the base of the formation,
- 10 c) drilling a plurality of second boreholes extending substantially outwardly into said formation from the tunnel(s) of step (b),
- d) injecting steam into said second boreholes, with the steam having a pressure above the fracture pressure of the subsurface formation,
- 15 e) maintaining the injection of step (d) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 20 f) releasing the pressure on the system of boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the second boreholes and thence to the lower portion of the first borehole,
- 25 g) collecting the liberated material.

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- h) repeating the injection/production cycle until the viscous material between at least some of the second boreholes is made mobile,
- 5 i) stopping the steam flow into the second boreholes,
- j) completing selected second boreholes as producer wells,
- 10 k) initiating a flooding procedure, selected from the procedures consisting of fire flood, water flood, steam flood, emulsion flood, and solvent flood, flowing from at least one injector well to at least one producing well, and
- l) collecting the liberated material.

15 5. The method of claim 4, wherein:

- a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- 20 b) the number of tunnels can vary from 1 to about 4,
- c) the spacing of the second boreholes varies from about 5 to about 300 meters,
- 25 d) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam injection rate at a water equivalent of greater than 15 m³/d/well,

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- 5
- e) the lower portion of the borehole or shaft is enlarged to form an operating chamber at the base of the formation,
 - f) the injection time period of step (e) is at least 5 days, and
 - f) the repeated injection/production cycles of step (h) number at least two.
6. The method of claim 5, wherein:
- 10
- a) the number of second boreholes varies from about 2 to about 20,
 - b) the steam injection rate has a water equivalent of from about 80 to about 350 m³/d/well,
 - c) the injection time period can vary from about 10 to about 100 days, and
 - d) the repeated injection/production cycles can number from about 2 to about 25.
- 15
7. A method for the in-situ recovery of viscous materials from a subsurface formation, comprising:
- 20
- a) forming a first borehole to the base of the subsurface formation to be exploited,
 - b) extending one or more tunnels from the first borehole or shaft at the base of the formation,
 - c) drilling a plurality of second boreholes extending substantially outwardly into said formation from the tunnel(s) of step (b).
- 25

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- d) completing at least one of said second boreholes as an injector well, while completing the remainder of said second boreholes as producer wells,
- 5 e) injecting steam via said first borehole and tunnels into said second boreholes completed as injector wells, with the pressure of the steam above the fracture pressure of the subsurface formation,
- 10 f) maintaining the injection of Step (e) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 15 g) releasing the pressure on the system of injector boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the first borehole,
- 20 h) repeating the injection/production cycle of steps (e) - (g) until hydrocarbon between at least some of said second boreholes is mobilized,
- 25 i) stopping the steam flow to the injector well and collecting the liberated material,
- j) initiating a flood procedure, selected from the procedures consisting of fire flood, water flood, steam flood, emulsion flood, solvent flood, flowing from an injector well
- 30 to a producer well, and

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k) collecting the liberated material.

8. The method of claim 7, wherein:

- 5 a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- b) the spacing of the second boreholes varies from about 5 to about 300 meters,
- c) the number of tunnels varies from 1 to about 4,
- 10 d) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam injection rate at a water equivalent of
- 15 greater than $15 \text{ m}^3/\text{d}/\text{well}$,
- e) the lower portion of the borehole or shaft is enlarged to form an operating chamber at the base of the formation,
- f) the injection time period of step (f) is at
- 20 least 5 days, and
- g) the repeated injection/production cycles of step (h) number at least two.

9. The method of claim 8, wherein:

- 25 a) the number of second boreholes varies from about 2 to about 20,
- b) the steam injection rate has a water equivalent of from about 80 to about $350 \text{ m}^3/\text{d}/\text{well}$,

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- c) the injection time period can vary from about 10 to about 100 days, and
- d) the repeated injection/production cycles can number from about 2 to about 25.

5 10. A method for the in-situ recovery of viscous materials from a subsurface formation, comprising:

- a) forming a first borehole to the base of the subsurface formation to be exploited,
- 10 b) extending one or more tunnels from the first borehole or shaft at the base of the formation,
- c) drilling a plurality of second boreholes extending substantially outwardly into said formation from the tunnel(s) of step (b),
- 15 d) injecting steam into said second boreholes, with the steam having a pressure above the fracture pressure of the subsurface formation,
- e) maintaining the injection of step (d) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 20 f) releasing the pressure on the system of second boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of said second boreholes and thence to the lower portion of the first borehole,
- 25

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- g) collecting the liberated material,
- h) repeating the injection/production cycle until the viscous material between at least some of the second boreholes is mobilized,
- 5 i) stopping the steam flow,
- j) completing selected second boreholes as producer wells,
- k) initiating a steam flooding procedure,
- 10 l) cyclically varying the steam pressure during the operation of step (k), and
- m) collecting the liberated material.

11. The method of claim 10, wherein:

- 15 a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- b) the number of tunnels varies from 1 to about 4,
- c) the spacing of the second boreholes varies from about 5 to about 300 meters,
- 20 d) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam injection rate at a water equivalent of
- 25 greater than 15 m³/day/well,
- e) the lower portion of the borehole or shaft is enlarged to form an operating chamber at the base of the formation,

- 5 f) the injection time period of step (e) is at least 5 days,
g) the repeated injection/production cycles of step (h) number at least two, and
h) The steam pressure of step (l) varies from about atmospheric to the operating pressure.

12. The method of claim 11, wherein:

- 10 a) the number of second boreholes varies from about 2 to about 20,
b) the steam injection rate has a water equivalent of from about 80 to about 350 m³/d/well,
c) the injection time period can vary from about 10 to about 100 days, and
15 d) the repeated injection/production cycles can number from about 2 to about 25.

13. A method for the in situ recovery of viscous materials from a subsurface formation, comprising

- 20 a) forming a first borehole to the base of the subsurface formation to be exploited,
b) extending one or more tunnels from the first borehole or shaft at the base of the formation,
c) drilling a plurality of second boreholes extending substantially outwardly into said formation from the tunnel(s) of step (b),
25 d) completing at least one of said second boreholes as an injector well, while completing

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the remainder of said second boreholes as producer wells,

- 5 e) injecting steam into said second boreholes designated injector wells, with the steam having a pressure above the fracture pressure of the subsurface formation,
- 10 f) maintaining the injection of step (e) for a time period so as to increase the temperature of that portion of the formation surrounding said second boreholes and any fracture fissures formed by the injection,
- 15 g) releasing the pressure on the boreholes, thus allowing any liberated material of reduced viscosity to move to the lower portion of the first borehole,
- h) repeating the injection/production cycle until hydrocarbon between at least some of said second boreholes is mobilized,
- 20 i) initiating a steam flooding procedure, and
- j) cyclically varying the steam pressure during the operation of step (i), and
- k) collecting the liberated material.

14. The method of claim 13, wherein

- 25 a) the subsurface formation containing viscous materials is approximately 30 meters or more below the surface,
- b) the number of tunnels varies from 1 to about 4,

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- 5 c) the spacing of the second boreholes varies from about 5 to about 300 meters,
- d) the injection stream has a steam quality of from about 50% to about 100%, a pressure of from about 17 kPa to about 44 kPa per meter of depth from the surface, and a steam injection rate at a water equivalent of greater than $15 \text{ m}^3/\text{d}/\text{well}$,
- 10 e) the lower portion of the borehole or shaft is enlarged to form an operating chamber at the base of the formation,
- f) the injection time period of step (f) is at least 5 days,
- 15 g) the repeated injection/production cycles of step (h) number at least two, and
- h) the steam pressure of step (j) varies from about atmospheric to the operating pressure.
15. The method of claim 14, wherein
- 20 a) the number of second boreholes varies from about 2 to about 20,
- b) the steam injection rate has a water equivalent of from about 80 to about $350 \text{ m}^3/\text{d}/\text{well}$,
- 25 c) the injection time period can vary from about 10 to about 100 days, and
- d) the repeated injection/production cycles can number from about 2 to about 25.

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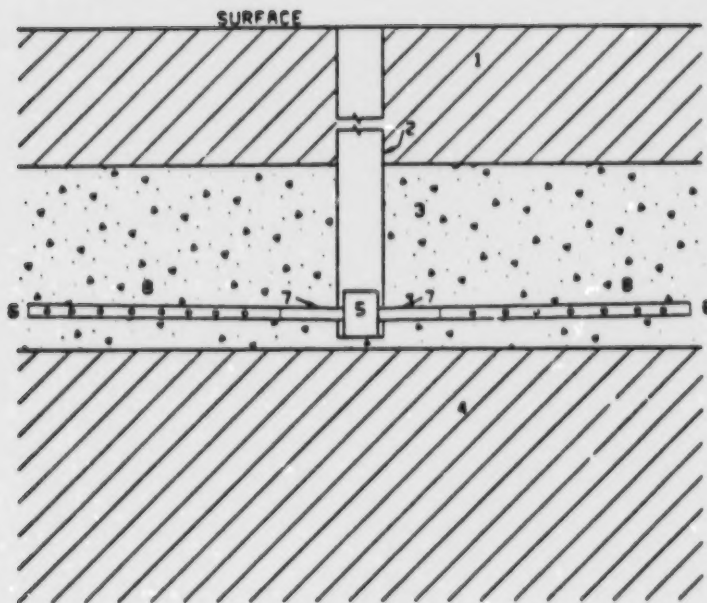


FIG. 1

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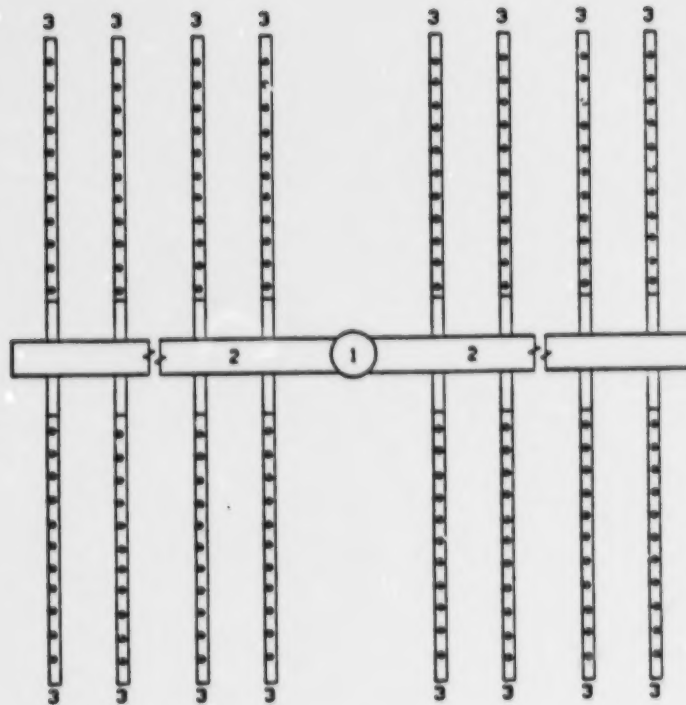


FIG. 2

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United States Patent [19]

Anderson

[11] Patent Number: 4,480,695

[45] Date of Patent: Nov. 6, 1984

[54] METHOD OF ASSISTING SURFACE LIFT OF
HEATED SUBSURFACE VISCOUS
PETROLEUM[75] Inventor: Donald J. Anderson, Newport Beach,
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[21] Appl. No.: 413,326

[22] Filed: Aug. 31, 1982

[51] Int. Cl.³ E21B 43/24

[52] U.S. Cl. 166/303; 166/50;

166/250

[58] Field of Search 166/303, 250, 50;

299/2, 5

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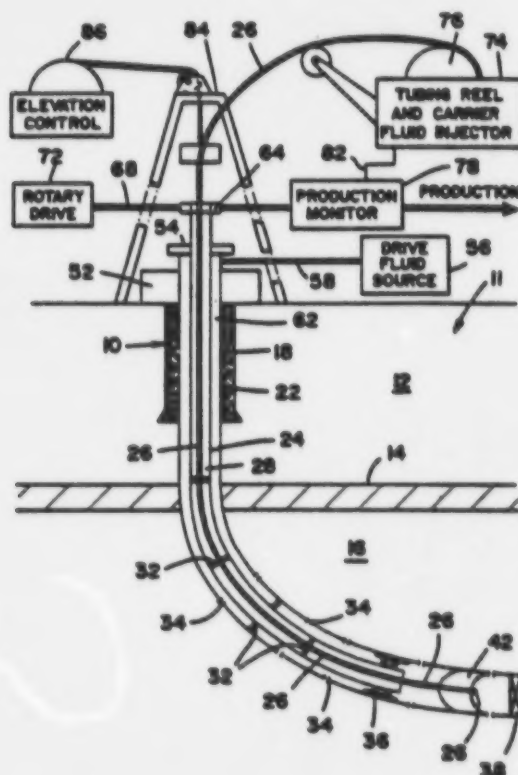
Primary Examiner—Stephen J. Novosad

Assistant Examiner—Mark J. Del Signore
 Attorney, Agent, or Firm—G. W. Wasson; Lewis S.
 Gruber; Edward J. Keeling

[57] ABSTRACT

A method and apparatus is described for producing viscous petroleum from a subsurface formation. The apparatus includes a generally horizontal cased well through the subsurface formation with injection and production tubings within the well. The casing is perforated and the inner tubings carry a movable packer and a rotatable agitator. The method comprises injecting a heating and drive fluid for moving heated viscous petroleum through the perforations in the casing and into the well for production to the wellhead. Production is monitored for the ratio of produced packer fluid and viscous petroleum. Based on that ratio, the packer is moved within the casing to positions along the horizontal well to maximize production of petroleum. The rotatable agitator assists in removal from the well bore of formation solids produced with the viscous petroleum.

5 Claims, 3 Drawing Figures



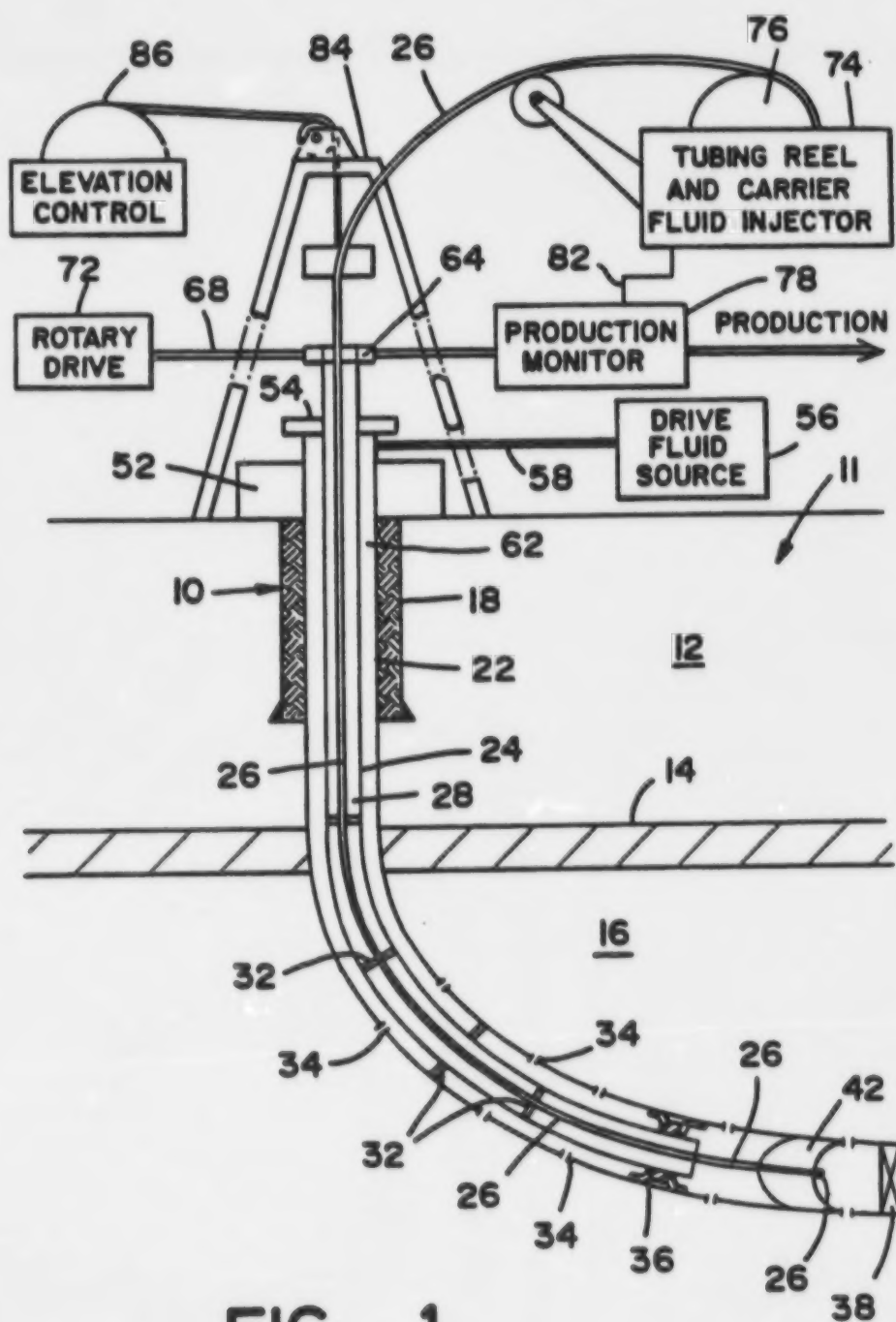


FIG - 1

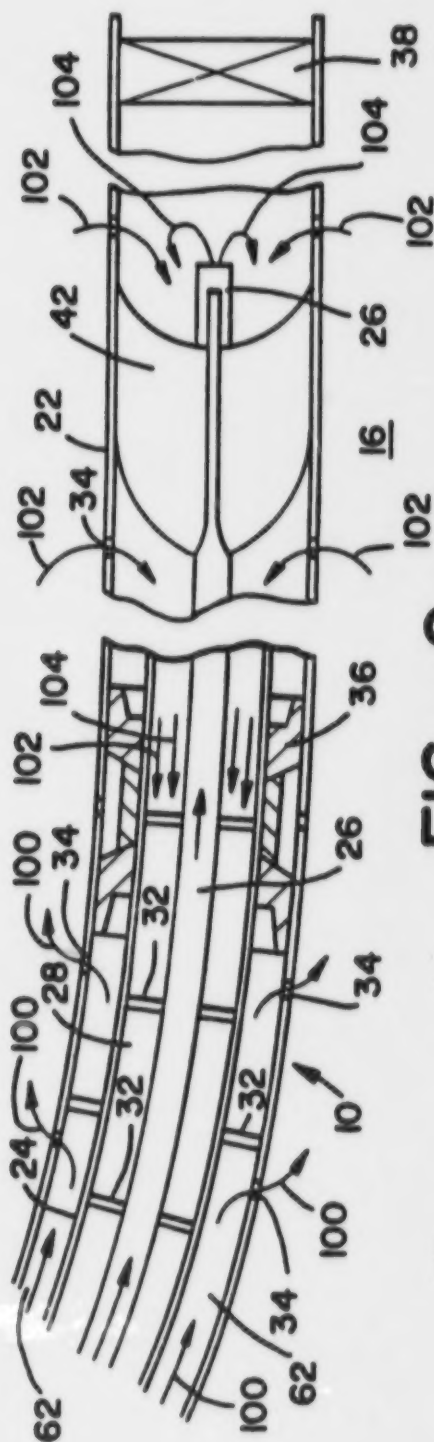


FIG - 2

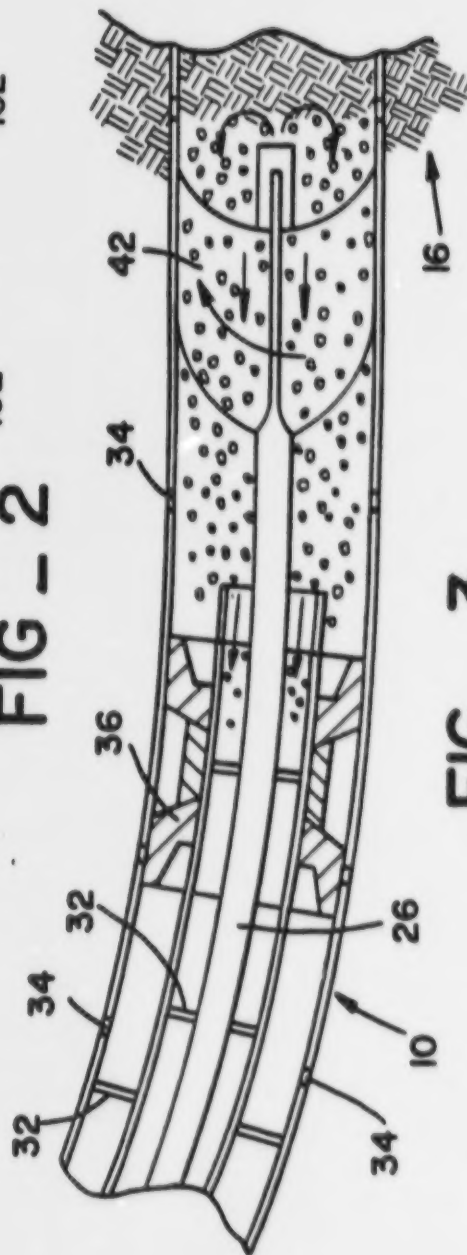


FIG - 3

METHOD OF ASSISTING SURFACE LIFT OF HEATED SUBSURFACE VISCOUS PETROLEUM

BACKGROUND OF THE INVENTION

This invention relates to recovering viscous petroleum from petroleum-containing formations. Throughout the world there are many deposits of high-viscosity crude petroleum in subsurface formations; some of these deposits are referred to as oil sands. In general, the crude petroleum in these deposits is not recoverable in its natural state through a well by ordinary production methods because there is insufficient or non-existent natural drive mechanisms to cause the petroleum to flow into a well.

There have been many in-situ well-to-well pilots proposed for shallow deposits of oil sands, all of which used some form of thermal stimulation after establishing communication between an injector well and a producer well. Many processes have been utilized in attempting to recover viscous petroleum from viscous oil formations of the Athabasca Tar Sands type, including the application of heat to such viscous petroleum formations by steam or underground combustion. The use of vertical slotted liners positioned in the viscous oil formation as a conduit for hot injection fluids has also been suggested; however, most of these methods have not been overly successful because of the difficulty of establishing and maintaining communication between an injector well and a producer well. Clearly, if one could eliminate the need to establish and maintain communication between an injector well and a producer well, regardless of the drive fluid or recovery technique employed, many of these viscous petroleum deposits could become potentially successful projects. Further, techniques are needed to assist in lifting the produced viscous petroleum to the wellhead and for clearing from the well formation solids produced with the viscous petroleum.

BRIEF DESCRIPTION OF THE INVENTION

The present invention is directed to a method of assisting the recovery of viscous petroleum from a petroleum-containing formation and is particularly useful in those formations where communication between an injector and a producer is difficult to establish and maintain. A hole is formed through the petroleum-containing formation and a generally horizontal, tubular pair of concentric conductors is inserted into the hole to provide a continuous, uninterrupted flow path from the wellhead through the generally horizontal tubular members in the formation and back to the wellhead. A hot fluid is flowed through the inner tubular member, returning to the surface via the annulus to heat viscous petroleum in the formation outside the outer tubular member to reduce the viscosity of at least a portion of the petroleum adjacent the outside of the outer tubular member with the intention of establishing a potential passage for fluid flow through the formation adjacent the outside of the tubular member. Alternatively, the hot fluid flow may be reversed by injecting down the annulus and returning to the surface through the inner tubular member.

The outer conductor of the tubular member may initially be perforated in the zone where recovery of the viscous petroleum is desired or the tubular member may

be subsequently perforated to provide passage ways between the formation and the tubular member.

After the viscous petroleum has been heated to become mobile, the lower portion of the tubular member is isolated from the fluid flow and opened to production of the heated petroleum. A diverter, for example, a movable packer, is placed within the tubular member between the inner and outer conductor to cause the hot fluid to pass out through the perforations into the formation, there acting as a drive fluid to force the heated petroleum toward the isolated open portion of the tubular member. In most cases the initial placement of the packer will be near the most downhole end of the well bore in order to maximize the pressure gradient between drive fluid and the formation, thereby facilitating early communication and petroleum production. The ratio of produced petroleum to drive fluid is monitored at the wellhead to recognize an indication of excessive pass-through of the drive fluid and, based on the monitored ratio, the diverter is moved within the tubular member to optimize the petroleum production rate and to minimize the drive fluid passthrough.

The diverter may be attached to the inner conductor to be movable back and forth within the outer tubing to maximize both the heating of the formation and the movement of the heated viscous petroleum into the producer well. In the event of an unwanted breakthrough of the drive fluid through the formation into the production portion of the well, the diverter can be moved to another location within the tubular member so as to maintain a desired formation heating and petroleum movement as the breakthrough heals.

A third hollow conductor is placed within the inner conductor to provide a path for circulating carrier fluid for the produced petroleum and drive fluid. The third hollow conductor may also be roostable to provide for clean-out operations within the tubular member thus avoiding blockage of the tubular member with produced sand and formation particles moved with the produced petroleum.

In the preferred form, the hot fluid which is flowed through the tubular member is steam, and the drive fluid used to promote movement of the petroleum is also steam. Under other conditions, the hot fluid and the drive fluid may be injected intermittently. The injectivity of the drive fluid into the formation is controlled to some extent by adjusting the condition of the hot fluid flowing through the tubular member. In this manner, the sweep efficiency of the drive fluid in the formation may be improved.

OBJECT OF THE INVENTION

An object of the invention is a method for producing viscous petroleum from a subsurface petroleum-containing formation using a single substantially horizontal well bore passing through the formation.

A further object of the present invention, in accord with the preceding object, is a method for heating, moving and producing viscous petroleum in a subsurface petroleum-containing formation using a concentric tubing well element within a well bore passing through the formation.

Another object of the present invention, in accord with the preceding objects, is an apparatus for use in a well bore passing through a formation containing viscous petroleum.

Further objects and features of the present invention will be readily apparent to those skilled in the art from

the appended drawings and specification illustrating a preferred embodiment wherein:

FIG. 1 is an elevational view, partially in section, illustrating one form of assembled apparatus.

FIG. 2 is a cross-sectional view through a subsurface earth formation illustrating injection, production, and lifting paths in accord with the method of the present invention.

FIG. 3 is a cross-sectional view similar to FIG. 2 and illustrating a method of operation in accord with the present invention in a manner to remove particulate material from the subsurface well bore.

DETAILED DESCRIPTION OF THE EMBODIMENTS OF THE INVENTION

Referring now to the drawings, and to FIG. 1 in particular, where the preferred embodiment of apparatus assembled in accordance with the invention is illustrated, FIG. 1 shows a well 10 drilled into an earth formation 11 having an overburden 12, an impervious layer 14 and a subsurface zone 16 containing viscous petroleum such as a tar sand. The well 10 includes an outer casing 18 cemented or completed to the formation overburden 12 and an inner casing 22 cemented to the outer casing 18. A first tubular conductor or producing string 24 is placed within the inner casing to provide a first hollow communication channel to the subsurface formations. A second tubular conductor or injection string 26 is placed within the first tubular conductor 24 to provide a second hollow communication shaft to the subsurface formations and to establish an annular space 28 between the first tubular conductor 24 and the second tubular conductor 26. Both the first and second tubular conductors are centralized within the well by suitable centralizers 32. At the downhole end of the well, the inner casing 22 is perforated at 34 in a series of places and a packer 36 is provided between the inside of the inner casing 22 and the outside of the first tubular conductor 24 in the annulus between these two members.

The bottom hole end of the inner casing 22 is completed with a cement plug 38 or other means for closing the end of the well. The bottom hole end of the second tubular conductor 26 is completed with a rotatable agitator or fishtail drill bit 42 which is adapted to be rotatable within the perforated inner casing 22 below the packer 36 and above the plug 38.

As illustrated in FIG. 1 the downhole end of the well 10 is deviated toward the horizontal to provide access to a larger horizontal portion of the zone 16 and to expose the formation surrounding the well to the heat from the fluids transported through the well and into the formation.

At the earth's surface the well is supplied with a wellhead 52 completing the outer casing 18 and the exterior of the inner casing 22. The wellhead is provided with a cap 34 permitting both rotational and longitudinal movement of the first tubular member 24, and the second tubular member 26 within that first tubular member, so that the concentric inner string of the two tubular members can be both rotated and inserted or withdrawn from the subsurface well. Below the cap 54 at the wellhead 52 a connection is made from a fluid drive source 56 through a conductor 58 to the annulus 62 between the inner casing and the tubular member 24.

The upper end of the first tubular conductor 24 is completed with a second cap 64 which provides for rotary and longitudinal movement of the tubular con-

ductor 26. The cap 64 also provides a fluid communication channel through conductor 66 from the annulus 28 between the first and second tubular conductors and is adapted to introduce rotational drive to the first tubular conductor 24 through shaft 68 from rotary drive 72. The position of the inner conductor 26 within the well is controlled by mechanism 74 which contains a reel 76 onto which the tubing 26 may be reeled and a means for injecting carrier fluid. The production of fluid through the conductor 66 is monitored by production monitor 78 to provide communications to the mechanism 74 through mechanical or electrical connection 82.

The movable portions of the wellhead are supported on a derrick 84 having suitable elevation control mechanisms 86 for raising or lowering the tubular members into and out of the well.

FIGS. 2 and 3 provide an enlarged view of the subsurface, and generally horizontal, portion of the well 10 in the subsurface zone 16. The packer 36 is movable with the first tubular conductor 24 into and out of the well independently of the second tubular conductor 26. In the same respect, the second tubular conductor is movable independently into and out of the well, below the packer 36 and above the plug 38. The inner tubular conductor 26 is rotatable to agitate materials within the well and below the packer 36 should such materials be produced with the fluid that moves into the perforations 34.

The apparatus illustrated in FIGS. 1 through 3 is adapted to complete the subsurface well and to be useful in the performance of the method of the present invention. It should be understood that other forms of apparatus to accomplish the same purposes are contemplated in accordance with the present disclosure. The apparatus itself permits the method of the present invention to be performed within the subsurface formations where viscous petroleum and/or tar sands may be produced if the petroleum deposits may be heated to increase their viscosity to permit them to flow through the formations and into the perforations of the well bore. For that purpose, the well construction and surface equipment of the present invention is adapted to provide for the flow of a drive fluid down through the annulus 62 in the path of the arrow generally shown at 100 and out the perforations 34 to accomplish heating of the formation 16 in the areas near, to and surrounding the well bore. As the formation petroleum is heated, it is moved by the drive fluids passing out through the perforations 34 to establish production of the mobile petroleum generally along the arrows 102 into the perforated inner casing 22 below the packer 36 and into the annulus space 28 between the inside of the first tubular conductor 24 and the second tubular conductor 26. Because the viscous petroleum still is under little subsurface pressure, it will probably not flow to the surface under its own pressure, and, for that reason a carrier fluid is pumped down the inside of the second tubular conductor 26 and out through the bottom hole end of that conductor, as shown by arrows 104, to mix with the produced petroleum to force the mixture of the carrier fluid 104 and production 102 up through the annulus 28. At the wellhead the produced carrier fluid and viscous petroleum are monitored by the production monitor 78 with the production going to a pipeline or storage system and, if possible, the separated carrier fluid being returned to the injector system 74.

The production monitor 78 is adapted to analyze the produced fluid to determine when excessive pusher

fluid 100 is passing in through the perforations at the downhole end of the well, as well as sensing the quantity of carrier fluid being produced at the surface. From that analysis it is possible to determine whether the drive fluid has begun to breakthrough the formation. If breakthrough occurs, the packer 36 is moved to another location along the well bore to cause the drive fluid to be injected into formations where the viscous petroleum has been heated to a mobile form thus forcing the produced fluids into the perforations at the lower end of the well and to maximize the production of viscous petroleum without excessive amounts of pusher fluid.

The subsurface apparatus is provided with the agitator or fishtail drill bit 42 to provide a means for removing the produced subsurface formation materials which may have passed through the perforations 34 along with the viscous petroleum. It has been known, particularly in the case of the tar sands, that the sand material is produced with the formation petroleum and that, as the sands are deposited within the subsurface well, the well becomes clogged and the petroleum can no longer be produced through the well. For the purpose of removing such formation materials, the drill bit 42 is placed at the downhole end of the second tubular conductor 26 and is adapted to be rotated within the first tubular conductor 24 to agitate the material which may have been deposited in the well bore. At the same time the carrier fluid can be injected through the inner conductor 26 to carry this formation sand or other materials to the earth surface for removal from the well.

One suitable form for accomplishing the removal of sands from the formation is to inject through the inner conductor 26 a stabilized foam. Such foam has superior lifting qualities for carrying the subsurface formation materials to the earth surface. The process of accomplishing that removal is described in U.S. Pat. No. 3,583,483, issued in the name of Robert W. Foote, for Method For Using Foam In Wells and assigned to the same assignee as the present application.

While certain preferred embodiments of the invention have been specifically disclosed, it should be understood that the invention is not limited thereto as many variations will be readily apparent to those skilled in the art and the invention is to be given its broadest possible interpretation within the terms of the following claims.

What is claimed is:

1. A method for assisting the recovery of viscous petroleum from a subsurface petroleum-containing zone comprising:

- (a) directionally drilling a well from the earth's surface into said subsurface petroleum-containing zone to position said well within said zone in a generally horizontal position;
- (b) casing said well and perforating said casing at least in said generally horizontal portion thereof;
- (c) placing a first tubular conductor within said casing and positioning the downhole end of said first tubular conductor adjacent to said perforations in

said casing in said petroleum-containing zone nearest to the earth's surface end of said casing;

- (d) injecting a hot fluid through said first tubular conductor into said perforated casing so as to heat said viscous petroleum adjacent to said perforated casing and to increase the mobility of said viscous petroleum to cause said heated viscous petroleum to flow into said casing through said perforations therein;
- (e) placing a second tubular conductor within said first tubular conductor and positioning the downhole end of said second tubular conductor generally adjacent to the downhole end of said casing;
- (f) placing a diverter between said casing and said first tubular conductor downhole from at least some of said perforations;
- (g) injecting a driving fluid between said casing and said first tubular conductor and out of said at least some of said perforations to force said viscous petroleum toward said downhole end of said first tubular conductor;
- (h) driving said viscous petroleum with said driving fluid toward said downhole end of said first tubular conductor;
- (i) injecting a carrier fluid through said second tubular conductor to flow up to the earth's surface in the annular space between the inside of said first tubular conductor and the outside of said second tubular conductor, said flowing carrier fluid carrying said heated viscous petroleum to the earth surface.

2. The method of claim 1 with the additional steps of monitoring said flowing carrier fluid and said produced viscous petroleum and controlling the flow of said carrier fluid through said second tubular conductor to maximize the production of said viscous petroleum.

3. The method of claim 2 with the additional steps of attaching said diverter to said first tubular conductor and positioning said downhole end of said first tubular conductor adjacent to other perforations in said casing closer to the downhole end of said casing in accordance with the monitored production of said carrier fluid and said produced heated viscous petroleum.

4. The method of claim 3 with the additional step of attaching a means for agitating to the downhole end of said first tubular conductor and rotating said first tubular conductor while moving said first tubular conductor within said casing adjacent to said perforations therein to loosen any subsurface materials produced through said perforations, and flowing said loosened subsurface materials to the earth's surface through said casing.

5. The method of claim 4 with the additional step of passing a foamed fluid through said second tubular conductor to carry subsurface materials produced through said perforations in said casing to the earth's surface.

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Alberta OIL SANDS

United States Patent [19]

Perkins

INFORMATION CENTRE

[11] Patent Number: 4,489,782

[45] Date of Patent: Dec. 25, 1984

[54] VISCIOUS OIL PRODUCTION USING ELECTRICAL CURRENT HEATING AND LATERAL DRAIN HOLES

[75] Inventor: Thomas K. Perkins, Dallas, Tex.

[73] Assignee: Atlantic Richfield Company, Los Angeles, Calif.

[21] Appl. No.: 560,697

[22] Filed: Dec. 12, 1983

[51] Int. Cl.³ E21B 43/24

[52] U.S. Cl. 166/248; 166/65 R

[58] Field of Search 166/248, 60, 65 R, 50, 166/61

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Primary Examiner—Stephen J. Novosad

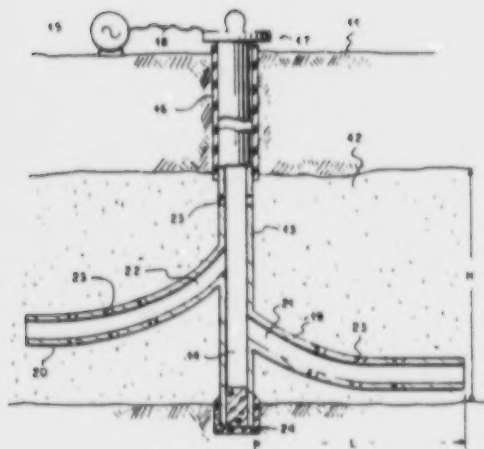
Assistant Examiner—Bruce M. Kisliuk

Attorney, Agent, or Firm—M. David Folzenlogen

[57] ABSTRACT

Improved electrical power utilization and increased oil production per producing well are achieved by specially completing a production well, applying electrical current through the production well to a subsurface formation, and producing oil from said formation. The production well extends essentially vertically from the surface and has one or more drain holes, preferably cased with tubular steel, extending laterally from the longitudinal vertical axis of the wellbore and into and traversing a part of the oil bearing formation. The length of the producing well traversing and being in fluid communication with the formation being substantially greater than the thickness of the oil bearing formation.

26 Claims, 2 Drawing Figures



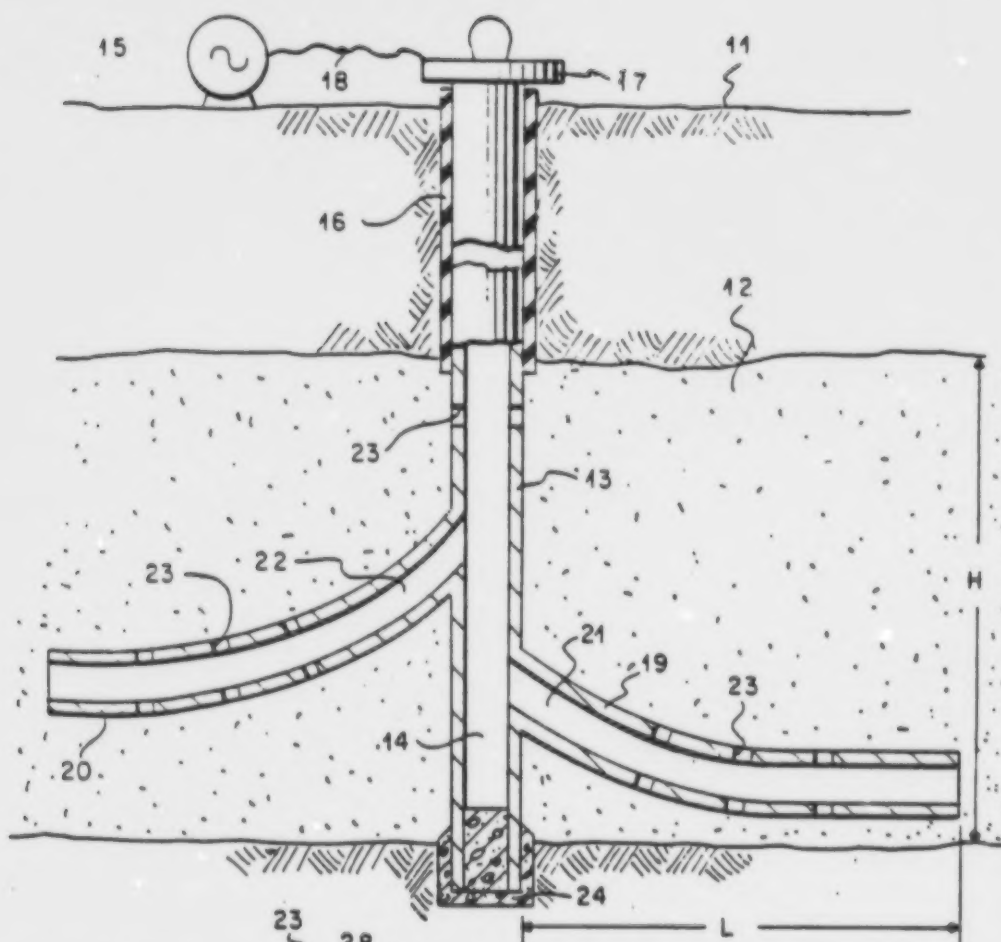


FIG. 1

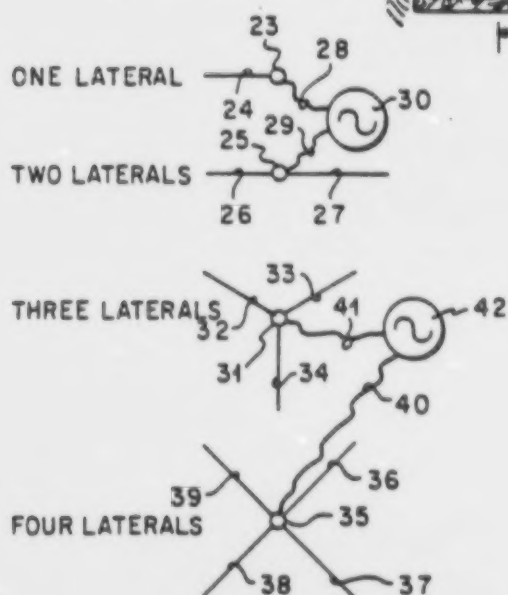


FIG. 2

VISCOUS OIL PRODUCTION USING ELECTRICAL CURRENT HEATING AND LATERAL DRAIN HOLES

BACKGROUND OF THE INVENTION

This invention pertains to an improved apparatus and method of producing viscous oil from a subsurface formation. More particularly, electrical formation heating and one or more slanted or horizontal boreholes extending from the same production well are combined to enhance the amount of oil produced with a given amount of electrical power.

For many years, it has been known that large deposits of relatively shallow, viscous oil are present in subterranean formations. Normally, the viscous oil is produced through a vertical production well. The well productivity is nearly inversely proportional to the viscosity of the oil. It has been proposed, for example, in U.S. Pat. Nos. 3,642,066; 3,874,450; 3,848,671; 3,948,319; 3,958,636; 4,010,799 and 4,084,637, to use electrical current to add heat to a subsurface pay zone containing tar sands or viscous oil to render the viscous hydrocarbon more flowable. Electrodes are connected to an electrical power source and are positioned at spaced apart points in contact with the earth. Currents up to 1200 amperes are passed between the electrodes. This heats oil in the formation. Electrical power utilizes energy from various sources. This energy is expended for viscous oil. Therefore, the relative success of electric heating is dependent on the amount of oil produced per unit of electric power applied. The effectiveness of the electrical process is partially limited by the effective radius of the borehole, for example, a radius of 0.5 foot, into which the oil flows from the formation.

In normal oil and gas producing operations, for various reasons, for example intersecting thin strata, it has been proposed to drill a slanted or essentially horizontal well. At an appropriate point in the earth, an essentially vertical borehole is deviated or drilled through an appropriate radius of curvature so as to extend laterally away from the vertical axis of the vertical borehole and extend either in a slanted manner or in an essentially horizontal manner through a portion of the formation.

It is the primary objective of this invention to increase oil production from a subsurface viscous oil bearing formation by combining electrical heating with one or more laterally extending slanted or horizontal boreholes having an effective production radius greater than normal.

SUMMARY OF INVENTION

In accordance with this invention, viscous oil is produced from a subsurface formation through a combined electrode-production well. The well is completed in the formation in a manner such that the effective radius of the well exceeds the effective radius of an essentially vertical well. The increase in effective radius is provided by one or more slanted or horizontal boreholes, hereinafter called drain holes, extending laterally into and across part of the formation. The drain hole or holes and any part of the vertical part of the well in the formation may be cased with tubular steel pipe which pipe or pipes serve both as electrode surfaces and as highly conductive flow passages in the formation flowing into the vertical part of the production well. Preferably the steel pipes will be perforated and will have a cylindrical flow passage with a diameter at least 0.25

times the diameter of the flow passage in the vertical part of the well. If the drain holes are not cased with metal, other forms of electrodes may be placed in the formation through the production well. Thereafter, electric current is passed from the production well through the formation to increase the temperature of oil therein and the heated oil is produced through the drain hole or holes and the same well. The increased effective radius of the well and possibly the increased electrode surface increases the effectiveness of electric power used to increase the temperature of the viscous oil. This increases the amount of oil produced. The total improvement of the combination of electric heating and the drain hole or holes depends on the completion technique and the length, number and spacing of the lateral drain holes, but production increases with the same amount of electrical power are expected to be up to 3 to 5 times and more greater than electric heating itself or drain holes by themselves. In addition, the other advantages of lateral drain holes are combined with electrical formation heating.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 shows a cross section of a wellbore passing through a subsurface formation containing viscous oil. The wellbore illustrates preferred features for accomplishing the objectives of this invention.

FIG. 2 is a diagrammatic top view illustrating various numbers of lateral drain hole configurations extending laterally from a wellbore.

DESCRIPTION OF PREFERRED EMBODIMENTS

In FIGS. 1 and 2, there are illustrated well completion techniques for transmitting electrical current power into a subsurface formation to heat viscous oil therein and for producing oil therefrom in a manner that enhances electrical power efficiency by increasing oil production. The improved combination of applying electric power and of producing oil utilizes one or more slanted or horizontal drain holes extending laterally from a vertical portion of a well into and traversing a part of the formation in a manner and of a length such that the effective radius of the production well is significantly greater than the effective radius of an essentially vertical well. The amount and degree of benefit derived depends on the total length of the part of the well located in the formation and on how the drain holes are completed. An optimum completion for two laterally extending drain holes is illustrated in FIG. 1 wherein a wellbore was drilled from surface 11 of the earth in standard fashion with a drilling or workover or recompletion rig (not shown) to extend essentially vertically downward into or through formation 12 which contains viscous heat sensitive oil. Two drain hole wellbores have been drilled laterally from a primary vertical wellbore in a manner such that after passing through a radius of curvature, the drain holes extend laterally away from the primary wellbore out into oil producing formation 12. The drain holes enhance the flow of oil from formation 12 by collecting the oil from a greater effective wellbore radius and conducting it to the primary wellbore. In conventional manner, the oil is pumped, lifted or flowed through the vertical part of the well to the surface of the earth. The parts of the vertical wellbore, if any, in the formation and the drain hole wellbores can be either cased or uncased, or cemented or

uncemented, with cement, plastic, metal, fiberglass and the like, provided that the wellbores remain open for production of oil from the formation. For example, some viscous oil bearing formations are unconsolidated and the wellbores must be supported to remain open. If the wellbores are not cased with metal pipe, an electrode or electrodes may be placed in the formation. Although this invention improves oil production without the drain holes being cased with steel pipe, it is to be understood that the degree of improved utilization of electrical power and increased oil production achieved with the combination of this invention is greatly enhanced if the drain holes and the part of the vertical wellbore, if any, extending into formation 12 are cased with steel pipe. Accordingly, the vertical portion of the well is cased with production casing 13 which may be casing, tubing, tubular pipe or any other similar form of tubular goods. Production casing 13 has cylindrical flow passage 14 which provides a flow passage leading to the surface of the earth into which tubing, a pump, a gas lift system or other production equipment may be installed. Production casing 13 is comprised of casing sections. The part of the casing in formation 12 may then be used as a tubular electrode and the upper part is used as an electric conductor for power source 15. In order to reduce overall impedance of the electric transmission system and reduce the magnetic hysteresis losses if alternating current is used, the upper part of the casing may be comprised of a nonmagnetic metal, such as, for example, stainless steel or aluminum. Corrosion and premature loss of power to the overburden above formation 12 or the underburden below the formation may be prevented by any standard technique, for example, electrical insulation 16. This outer insulation may be comprised of cement, coatings, pipe wrapping, extruded plastic, heat shrinkable sleeves, or other similar insulating or nonconductive corrosion protection materials. Some of the insulation may be pre-applied. Production casing 13 is shown connected in typical fashion to casing hanger 17 represented schematically. The casing hanger is electrically connected via conductor 18 to power source 15. The power source is connected to one or more other electrodes (not shown) and preferably to one or more other combination production electrode-drain hole wells. The power source is capable of supplying either DC, pulsating DC, or single phase, 3-phase or other poly-phase, uniform or eccentric AC power at voltages up to several thousand volts and currents up to 1200 amperes and higher. Alternating current is preferred.

In FIG. 1, the thickness of the formation is represented by height "H" and the drain hole wellbores extend laterally into formation 12 by distance "L". The ratio of L/H is significant to the objectives of this invention as will hereinafter be shown in connection with FIG. 2. The drain holes are cased with tubular steel pipes 19 and 20 which may be casing, tubing, drill pipe or any other form of steel tubular goods. Steel pipes 19 and 20 have cylindrical flow passages 21 and 22 respectively which fluidly communicate with flow passage 14 in production casing 13. Preferably, the parts tubular steel members 13, 19 and 20 located in the formation are perforated with perforations 23. The drain holes pipes are, therefore, in fluid communication with the formation and collect oil flowing from the formation into the pipes. The oil flows through cylindrical passages 21 and 22 into flow passage 14. Since the rate of flow into the drain holes is a significant factor in the degree of im-

proved results achieved from the combination of this invention, it is highly desirable that drain hole pipes be a part of the production well electrode. This increases the electrode surface area while spreading the maximum points of electrical resistance heating over a wider area of the formation and heating oil at the points of highest flow resistance. Accordingly, it is preferred that the drain hole pipes be electrically connected to production casing 13. Moreover, although it is unlikely that cylindrical flow passages 21 and 22 will be a factor limiting the rate of oil drainage it is preferred that the diameter of these flow passage be at least as great as 0.25 of the diameter of flow passage 14.

For illustrative purposes, the vertical part of the production well extends through formation 12 and drain hole pipe 19 and 20 are shown connected to production well casing 13 in the formation, but this is not necessarily the case. It is difficult to install tubular pipe in drain holes having a radius of curvature of less than 30 feet. Even curvatures of 30 feet require special knuckle-type bendable pipe joints, for example U.S. Pat. Nos. 3,349,845 and 3,398,804. More standard types of pipes may require a radius of curvature of 300 feet or more and thickness or height "H" of the pay zone of formation 12 may be less than three hundred feet. Accordingly, the point of juncture of the drain hole pipes and production casing 13 may be in the overburden above the formation and the vertical part of the well may not extend into formation 12. In such case, the outer surface of the drain hole tubular pipes in the overburden may also be insulated to prevent loss of electrical power.

In FIG. 2, a top plan view of flow oil production wells with different numbers of drain hole configurations is shown. Well 23 has one laterally extending drain hole 24. Well 25 has two lateral drain holes 26 and 27 at angles of 180° to each other. Wells 23 and 25 are electrically connected via conductors 28 and 29 to power source 30. Well 31 has three lateral drain holes, 32, 33 and 34 at angles of 120° to each other. Well 35 has four lateral drain holes, 36, 37, 38 and 39 at angles of 90° to each other. Wells 31 and 35 are electrically connected via conductors 40 and 41 to power source 42. These four configurations illustrate the it is desirable in a given well to space the drain holes as far apart as practical. As voltage is maintained across wells 23 and 25 and wells 31 and 35 current flows between the wells and heats the viscous oil in the formation thereby reducing its viscosity. For example, a dead viscous oil sample had a viscosity of 15,000 centipose at 85° F., 1,000 centipose at 135° F. and 170 centipose at 185° F. The advantages of the combination of production well electrodes with drain holes can be seen in Table 1 which is based on electrolytic models scaled roughly to the UGNU reservoir in Alaska. The four lateral drain hole configurations of FIG. 2 were used assuming that the vertical portion of the well extends through the formation. In the model, the drain holes were centered mid depth of a reservoir with "H" equal to 150 feet. Three drain hole lengths of feet, 300 feet and 450 feet were used. It was assumed that the drain holes were perforated, had an effective radius of 0.5 foot and joined production well casing 13. Steady state flow from an outer radius of 1000 feet was used. The results shown in Table 1 were obtained.

TABLE I

PRODUCTIVITY RATIO				
Well with Drainholes				
Vertical Well				
L/H	1 lateral	2 laterals	3 laterals	4 laterals
A. Drain Holes Without Electricity				
3	2.43	3.50	4.37	4.60
2	1.98	2.74	3.34	3.48
1	1.50	1.93	2.27	2.32
0	1	1	1	1
B. Drain Holes With Electricity				
3	7-12	10-17	13-21	14-23
2	6-10	8-14	10-16	10-17
1	4-7	6-10	7-11	8-13
0	3-5	3-5	3-5	3-5

In operation, the producing area is prepared for the process of this invention. Preparation of the producing area will include selection of the desired number of combined electrode-lateral drain hole wells to be completed in accordance with the principles set forth above and the well patterns for producing and injection wells. This selection will partially depend on the type and number of phases of the electrical power to be applied. For example, direct current may be used in some parts of the formation while alternating current is applied in other parts. By way of further example, a six phase configuration, with or without neutral voltage may be employed in conjunction with a hexagonal well pattern. If desired, the producing area may be preheated with electricity, steam or other form of heat. Sometimes there may be insufficient pressure differential between the formation and the producing wellbore. External energy, for example, water or flue gas injection, may be added to pressurize the formation.

When the producing area is prepared and at least one combined electrode-lateral drain hole well is completed in the formation, voltage and current will be generated in a conventional manner. Electrical voltages varying from a few hundred volts to 1000 or more will be applied to the electrode production and injection wells and currents from few hundred to 1000 or more amperes will be flowed between the electrodes. Most of the power will flow through the formation between the electrodes. Since there will be a high current density adjacent the combined electrode-lateral drain hole producing well or wells, the temperature will tend to increase more rapidly near the producing wells thereby stimulating increased oil production. Simultaneously, hot water or steam may be injected into the formation at a pressure suitable to confine the electrically heated oil and maintain sufficient pressure to force oil toward the producing wells.

From the foregoing, it can be seen that this disclosure achieves the purposes previously mentioned and that this invention is suitable for use in many of the prior art systems. Although this invention has been described with a certain degree of particularity, it is understood that the present disclosure has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of this invention.

I claim:

1. A method of producing oil from a subsurface formation containing viscous oil comprising drilling and completing a first well in said formation in a manner such that said well has an essentially vertical portion and at least one drain hole extending laterally from the

longitudinal axis of said portion of said first well, at least a part of said laterally extending drain hole traversing a part of said formation, said vertical portion of said first well being in communication with the surface of the earth, said drain hole being in fluid communication with said vertical portion of said first well, said first well being completed in said formation in a manner such that the effective radius of said well is substantially greater than the effective radius of a vertical well completed in said formation, applying electric current through said first well into said formation, and producing oil through said drain hole and said first well.

2. The method of claim 1 wherein said drain hole is cased with tubular steel pipe.

3. The method of claim 2 wherein the diameter of the cylindrical passage through said tubular pipe in said drain hole is at least as great as 0.25 times the diameter of the flow passage through said vertical portion of said first well.

4. The method of claim 1 wherein said vertical portion of said first well extends into and traverses at least a part of said formation.

5. The method of claim 4 wherein said drain hole is cased with tubular steel pipe.

6. The method of claim 5 wherein the diameter of the cylindrical passage through said tubular pipe in said drain hole is at least as great as 0.25 times the diameter of the flow passage through said vertical portion of said first well.

7. The method of claim 1 wherein said first well is completed in a manner such that at least two drain holes extend laterally from the longitudinal axis of said vertical portion of said first well at least a part of each of said laterally extending drain holes traversing a part of said formation, each of said drain holes being in fluid communication with said vertical part of said first well.

8. The method of claim 7 wherein said drain holes are cased with tubular steel pipes.

9. The method of claim 8 wherein the diameter of the cylindrical passages through said tubular pipes in said drain holes are at least as great as 0.25 times the diameter of the flow passage through said vertical portion of said first well.

10. The method of claim 7 wherein said vertical portion of said first well extends into and traverses at least a part of said formation.

11. The method of claim 10 wherein said drain holes are cased with tubular steel pipes.

12. The method of claim 11 wherein the diameter of the cylindrical passages through said tubular pipes in said drain holes are at least as great as 0.25 times the diameter of the flow passage through said vertical portion of said first well.

13. The method of claim 1 wherein a second well is drilled and completed in said formation in a manner such that said second well has an essentially vertical portion and at least one drain hole extending laterally from the longitudinal axis of said portion of said second well, at least a part of said laterally extending drain hole traversing a part of said formation, said vertical portion of said second well being in communication with the surface of the earth, said drain hole being in fluid communication with said vertical portion of said second well, said second well being completed in said formation in a manner such that the effective radius of said second well is substantially greater than the effective radius of a vertical well completed in said formation,

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applying electric current through said second well into said formation, and producing oil through said drain hole and said second well.

14. The method of claim 13 wherein said drain hole extending from said second well is cased with tubular steel pipe.

15. The method of claim 14 wherein the diameter of the cylindrical passage through said tubular pipe in said drain hole extending from said second well is at least as great as 0.25 times the diameter of the flow passage through the vertical portion of said second well.

16. The method of claim 13 wherein said second well is completed in a manner such that at least two drain holes extend laterally from the longitudinal axis of said vertical portion of said second well, at least a part of each of said laterally extending drain holes traversing a part of said formation, each of said drain holes extending from said second well being in fluid communication with said vertical part of said second well.

17. The method of claim 16 wherein drain holes extending from said second well are cased with tubular steel pipe.

18. The method of claim 17 wherein the diameter of the cylindrical passage through said tubular pipe in said drain hole is at least as great as 0.25 times the diameter of said tubular pipe of the portion of said tubular pipe of said first well extending into said formation.

19. The method of claim 13 wherein said first and said second wells are completed in a manner such that at least two drain holes extend laterally from the longitudinal axis of said vertical portions of said first and second wells, at least a part of each of said laterally extending drain holes traversing a part of said formation, each of said drain holes extending from said first well being in fluid communication with said vertical part of said first well, and each of said drain extending from said second well being in fluid communication with said vertical part of said second well.

20. The method of claim 19 wherein said drain holes extending from said wells are cased with tubular steel pipe.

21. The method of claim 20 wherein the diameter of cylindrical passages through said tubular pipes in said drain holes in said wells are at least as great as 0.25 times the diameter of the flow passages in the vertical portions of said wells.

22. A combination electrode and producing well for passing current into a subsurface viscous oil bearing

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formation and producing oil from said formation comprising a wellbore extending essentially vertically from the surface into the earth, said vertical borehole being cased with tubular metallic pipe, at least one drain hole extending laterally from the vertical longitudinal axis of said vertical borehole into and traversing a part of said viscous oil bearing formation, said drain hole being cased with tubular steel pipe, said tubular steel pipe in said drain hole being electrically connected to an electrical power source near the surface of the earth, said tubular steel pipe being in fluid communication with said tubular metallic pipe in said vertical wellbore and being in fluid communication with said formation, the length of said well in said viscous oil bearing formation being substantially greater than the thickness of said viscous oil bearing formation, and the lower portion of said wellbore pipe being electrically connected to an electrical power source.

23. The combination electrode and producing well of claim 22 wherein the diameter of the cylindrical passage in said tubular steel pipe in said drain hole is at least as great as 0.25 times the diameter of the cylindrical passage in said tubular metallic pipe in said vertical wellbore at the point where said drain hole is in fluid communication with said tubular metallic pipe.

24. The combination electrode and producing well of claim 23 wherein said essentially vertically extending wellbore extends into said viscous oil bearing formation.

25. The combination electrode and producing well of claim 22 wherein at least two drain holes extend laterally from the longitudinal axis of said vertical wellbore into and traversing a part of said viscous oil bearing formation, said drain holes being cased with tubular steel pipe, said tubular steel pipes in said drain holes being electrically connected to an electrical power source near the surface of the earth, and being in fluid communication with said tubular metallic pipe in said vertical wellbore and being in fluid communication with said formation.

26. The combination electrode and producing well of claim 25 wherein the diameters of the cylindrical passages in said tubular steel pipes in said drain holes are at least 0.25 times the diameter of the cylindrical passage in said tubular metallic pipe in said vertical wellbore at the points where said drain holes are in fluid communication with tubular metallic pipe.

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[54] TAR SAND PRODUCTION USING THERMAL STIMULATION

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[21] Appl. No.: 492,865

[22] Filed: May 9, 1983

[51] Int. Cl.: E21B 43/34

[52] U.S. Cl.: 166/303; 166/306; 166/30; 166/37; 166/180

[58] Field of Search: 166/50, 57, 157, 180, 166/187, 191, 302, 303, 306

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Primary Examiner—Stephen J. Novosad

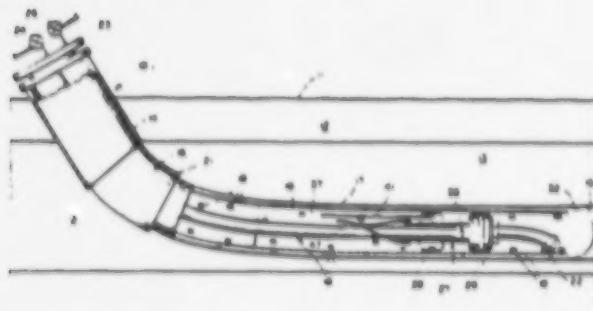
Assistant Examiner—William P. Neuder

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[57] ABSTRACT

Method and apparatus for recovering hydrocarbons from a subterranean formation in which a well completion, including a well liner, lies in a generally horizontal disposition within the hydrocarbon producing layer. The liner encloses conduit means for delivering a stream of a hot stimulating agent to the well's remote or injection end, and means for regulating the production of bitumen emulsion from the production end. A fluid impervious barrier is carried on and depends from the conductor means and forms a transverse fluid barrier within the liner. The conductor member is fixed within the liner whereby to serve as a means for introducing the thermal stimulating agent or medium to the substrate as well as functioning as a guide for the movable fluid impervious barrier. By adjusting the longitudinal position of said barrier, the hot stimulating agent is more effectively introduced to the substrate to improve the sweeping action thereof.

4 Claims, 3 Drawing Figures



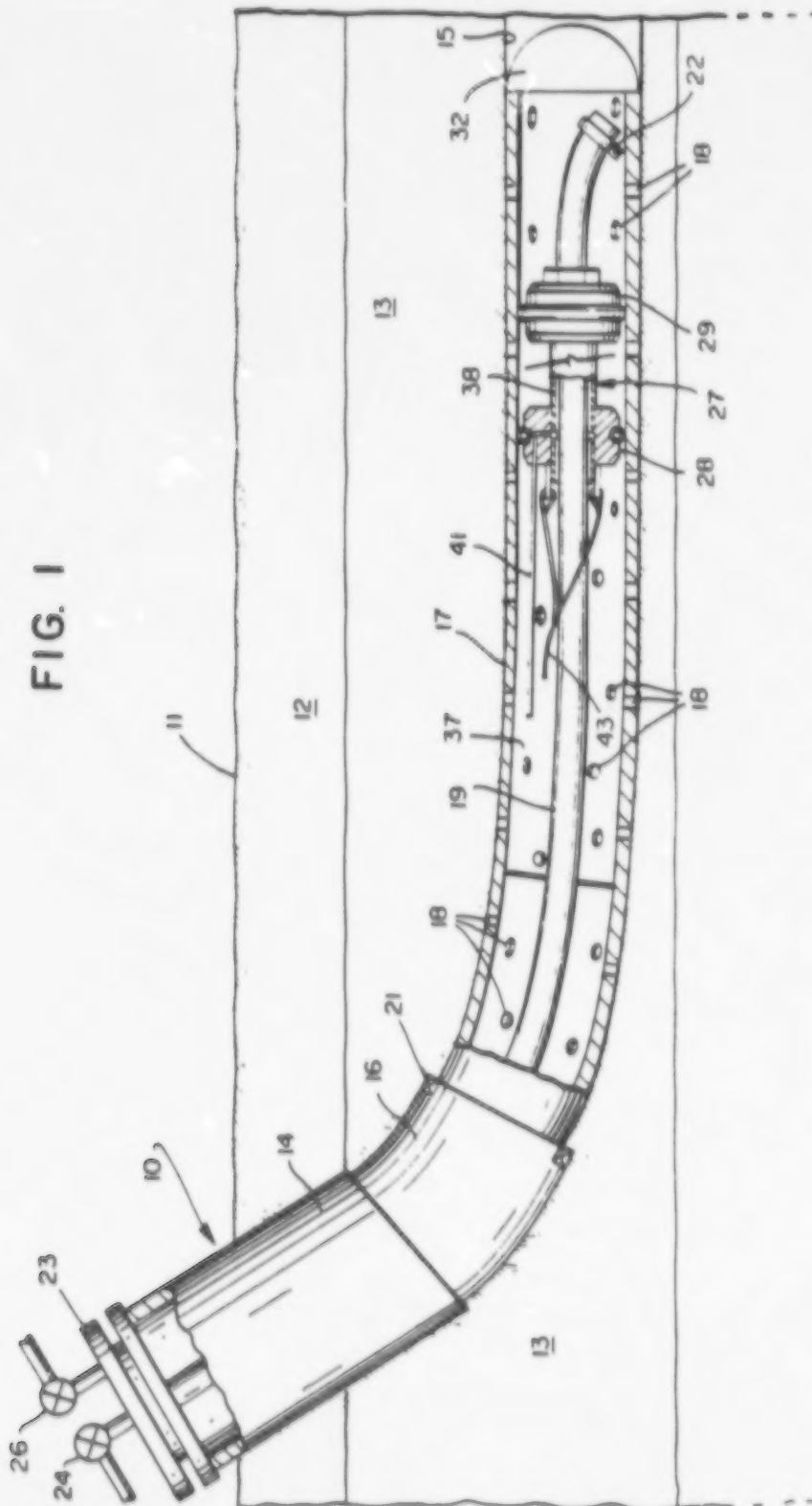


FIG. 2

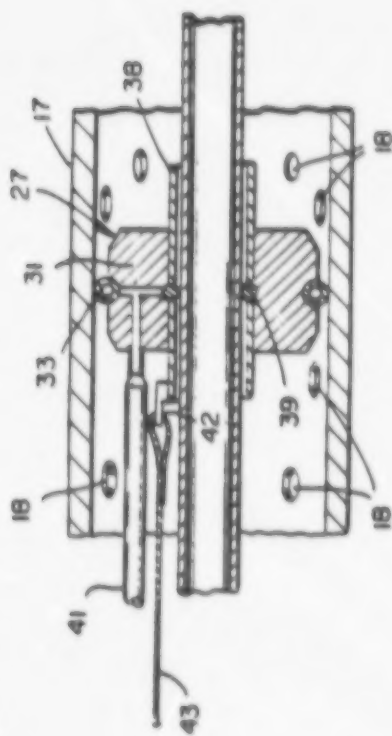
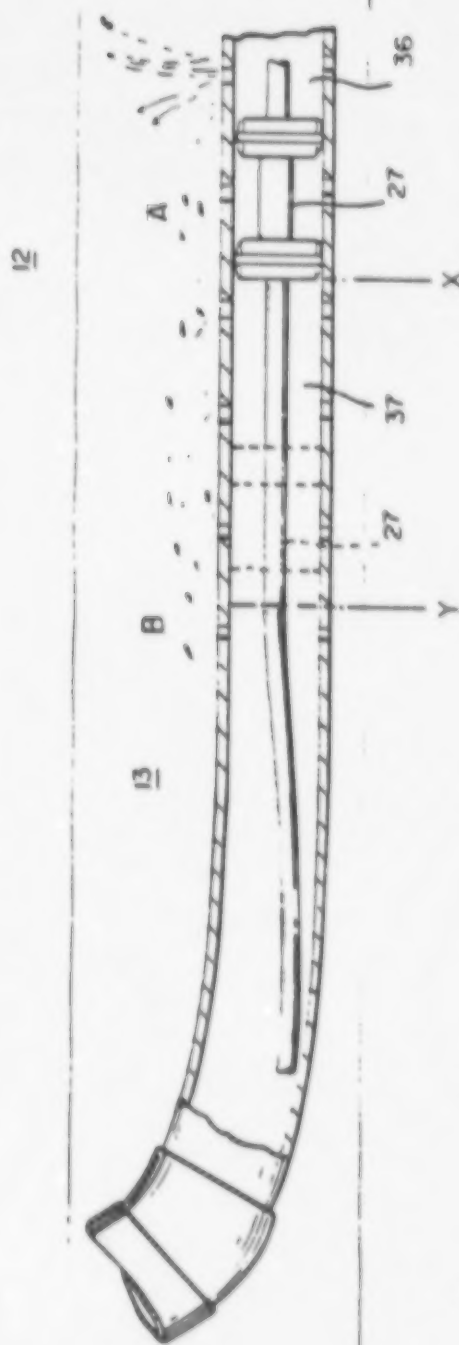


FIG. 3



TAR SAND PRODUCTION USING THERMAL STIMULATION

BACKGROUND OF THE INVENTION

In the production of viscous hydrocarbons such as heavy crude, or bitumen from tar sands, it is necessary to thermally stimulate the relatively viscous hydrocarbon material such that it can flow and be withdrawn from the substrate as an emulsion. Usually, thermal stimulation comprises the introduction of hot aqueous heating mediums such as pressurized steam, into the substrate by way of an injection well to contact the bitumen.

This stimulating step over a period of time fluidizes the bitumen and releases it from the tar sand. The steam also establishes a pressure front whereby to urge the now flowable hydrocarbon emulsion or mixture toward one or more production wells.

The present method and apparatus are applicable to producing either bitumen from tar sands, or heavy viscous crude oil from a reservoir thereof within the substrate. To simplify the following description, only bitumen will be referred to as the produced material.

Since the hot steam will condense under proper conditions, the product formed by the bitumen comprises in essence an aqueous mixture. Although this said product could be considered as being an emulsion, depending on the condition thereof, it will be hereafter referred to as an aqueous bitumen mixture.

In one method adapted to this type of viscous hydrocarbon production, it is found practical to utilize a single well which is sequentially heated and produced on the cyclical principle. More specifically, the environment around the well is initially preheated to put the bitumen into a flowable state. Thus, during a soak period, heat is absorbed into the substrate about the well causing the hot flowable material to gravitate toward the well. Thereafter, the stimulating step is continued in such manner that the hot mixture will continue to flow and to be produced from the well.

When over a period of time, pressure within the substrate deteriorates or the production flow decreases, it is necessary to recommence the cycle by further introduction of stimulating medium. As a sufficiently high pressure is reestablished and the bitumen solution is again caused to flow, steam injection is discontinued or minimized. Further controlled draw-down of the bitumen mixture can now be resumed.

This cyclical process can be continued indefinitely until the substrate adjacent to the well becomes exhausted of producible hydrocarbon product. Because of its general character, the method is referred to generally as the huff and puff process. It is found to function efficiently particularly when the stimulating medium is steam.

In an alternate method for producing viscous hydrocarbons from this type of substrate, a plurality of generally vertical wells are drilled in a desired surface pattern. Thereafter, a stimulating fluid such as steam is injected over a period of time into the substrate through a centrally located injector well.

The heated or stimulated area about the well will be progressively widened, thereby establishing a pressure front which drives flowable bitumen mixture toward the surrounding producing wells.

This process enjoys the advantage of being practiced by the continuous introduction of the hot stimulating medium. It thus yields a continuous out-flow.

It is found desirable toward achieving an improved bitumen production rate, to utilize a generally horizontally disposed well for producing from a relatively thin hydrocarbon containing layer. Due to the nature of this type of well, the latter must as herein noted operate on a cyclical basis to achieve an appreciable outflow of bitumen mixture. Since cyclical operation amounts to a disruption of the producing phase it constitutes a less than economical expedient.

To realize an improved production rate from a horizontal well of the type contemplated, there is presently provided an efficient method and apparatus for producing a hot aqueous bitumen mixture from a tar sand or similar environment. The process is effectuated through a single, elongated horizontal well which lies in at least a portion of a tar sand layer, preferably in a direction concurrent with the layer's direction.

Both the horizontal well itself and the adjacent substrate, are initially preheated to establish a favorable operating temperature at which fluidized bitumen mixture becomes mobile. The well includes means to establish a pattern of paths through the productive layer along which the bitumen mixture will readily flow. Said paths thereby communicate a relatively high pressure injection area where the stimulating fluid is introduced, with the low pressure area in the well toward which the bitumen gravitates.

Thereafter, and subsequent to the preheating step, the horizontal well is produced by regulated further introduction of hot stimulating fluid. This latter injection, together with control of the well back pressure, causes fluidized bitumen mixture to be urged toward the well producing end. At high temperature conditions, and after a period of operation, all or a part of the stimulating steam will be produced with the mixture, thereby giving an indication of a decrease in the production rate.

To maintain a favorable production output, the substrate is most effectively swept clean of removable bitumen by adjusting the injection pattern of stimulating fluid. The latter is achieved by diverting the flow of the stimulating steam whereby to change the relationship between the high pressure or injection under the well liner, and the low pressure or production end thereof.

It is therefore an object of the invention to provide a method and apparatus for improving the production of viscous hydrocarbon fluid from the subterranean reservoir in which the hydrocarbon fluid is locked. A further object is to provide a method and apparatus for stimulating and producing a well aligned substantially horizontally in the formation, and containing a relatively viscous hydrocarbon. A still further object is to provide a method and apparatus for the continuous production of a viscous hydrocarbon fluid from a single well disposed substantially horizontally through a productive formation.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevation view in cross-section of a horizontal well of the type contemplated.

FIG. 2 is an enlarged segmentary view in cross-section of a portion of FIG. 1.

FIG. 3 is a schematic representation of the well shown in FIG. 1.

Referring to the drawings, well 10 of the type contemplated is shown which enters the ground vertically,

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or preferably at an angle to the surface 11. Wellbore 15 is initially started through overburden 12 which overlies the productive or tar sand layer 13.

Thereafter, partway through overburden layer 12, bore 15 is deviated in the manner that at least a segment of the bore lies in a generally horizontal relationship with respect to layer 13 as well as to the earth's surface 11. Further, the well's horizontal segment is preferably positioned to the depth whereby to be adjacent to the lower border of the generally horizontal, hydrocarbon containing layer 13. Following the usual drilling practices, wellbore 15 is provided at its upper end with a series of casing lengths 14 and 16 which are fixed in place.

An elongated liner 17 is inserted through the respective casings 14 and 16, and is supported in casing 16 by a liner hanger 21. The latter is structured to permit passage of bitumen emulsion, or hot stimulating fluid therethrough during the producing or injecting stages of the operation. Liner 17 can be provided at its forward or remote end with a bull nose 32 or similar means to facilitate its being slidably inserted into the wellbore.

Structurally, liner 17 comprises a steel, pipe-like member being perforated as required along that portion of the wall which lies within the tar sand layer 13. The perforations 18 can take the form of a series of holes in the liner wall. Alternately they can comprise slotted openings which extend either longitudinally or peripherally about the liner. Further, said perforations, if in the form of holes, can be formed either before or after the liner is set within the bore 15.

In any event, liner openings 18 are adequate to allow the discharge of heating medium therethrough and into the adjacent tar sand substrate 13. Further, they allow the return flow, or the entry of a hot aqueous bitumen mixture through the same wall openings after said mixture achieves a flowable state.

An elongated fluid carrying conductor 19 is disposed internally of liner 17. Conductor 19 when fully inserted, rests on the liner wall. Said conductor is constructed preferably of continuous tubing, connected pipe, or the like.

Conductor 19 is capable of carrying a pressurized (about 200 to 500 psi) stream of hot stimulating fluid such as steam, hot water, or either of said elements having appropriate chemicals intermixed therewith to facilitate the producing step. The composition of the injected fluid will depend to a large extent on the particular conditions encountered in the substrate being stimulated. Operationally, conductor 19 not only carries the stimulating fluid but also functions as a guide member as will be hereinafter noted.

The upper external ends of the respective liner 17 and conductor 19, are provided with a closure means 23 such as a well head. The latter includes valves 24 and 26 which are operable to permit selective and controlled communication of the individual liner passages with a source of the pressurized stimulating fluid.

Conductor 19 by and large rests on the lower wall of liner 17. However, to facilitate its function as a guide member, the remote end of the conductor which is disposed adjacent to the remote end of the liner, is fastened in place with a suitable bracket 22 depending from the inner wall of liner 17.

A fluid diverter 27 means is operably positioned within liner 17 and slidably carried on the outer surface of conductor 19. One embodiment of flow diverter means 27, as shown in FIG. 1, comprises one or more

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packers 28 and 29, or similar form of apparatus often used in downhole operations and which are selectively actuatable to releasably engage adjacent liner walls.

Referring to FIG. 2, a packer of the type contemplated includes in essence a body 31 having a diameter which is less than the internal diameter of liner 17. The outer edge periphery of said body 31 is provided with a peripheral groove which retains an inflatable, expandable annular member 33 therein.

In the deflated condition, said inflatable member is contracted to the extent that the packer is spaced from the liner 17 inner wall. It can thus be readily moved longitudinally through the liner. In the expanded condition, however, inflatable member 33 will engage the adjacent walls of liner 17 thereby firmly positioning the packer member. It will concurrently form a fluid tight annular seal which in effect segregates the liner length into an injection segment 36, and a production segment 37.

Packer body 31 is provided with a central passage or opening which is of sufficient size to slidably register along conductor 19 outer surface. Preferably, said central opening can be provided with a cylindrical sleeve 38 or the like. The latter registers about the conductor outer surface to facilitate the slidable movement of the packer unit along conductor 19 as will be hereinafter noted.

To facilitate the sealing function of packer 28, body 31 can be provided with an inner, inflatable ring 39. The latter is communicated with the outer expandable member 33. Both said members are in turn communicated through external connection which engages elongated flexible conduit 41. The latter extends to well head 23 and can thus be communicated with a source of a pressurized actuating fluid.

Operationally, flow diverter 27 is rigidly fixed at a desired location, by introducing pressurized actuating medium into both the expandable member 33 and the central inflatable ring 39. Said members thus form annular concentric fluid tight seals within liner 17, thereby defining a fluid tight transverse barrier therein. Further, from an operational consideration, the expanded diverter as noted segregates the length of liner 17 into two distinct parts, i.e. the remote or injection segment 36 and the production segment 37.

The forward end of the fluid diverter 27 is provided with connector means 42 such as a ring, shackle or the like which is adapted to engage a pulling mechanism. The latter can comprise an elongated cable 43 which connects to the ring at one or more peripherally spaced points. Cable 43 is of sufficient length to reach well head 23 whereby to be reeled in to draw the packer member longitudinally through liner 17.

In one embodiment of the fluid diverter 27, the latter can comprise as shown in FIG. 1, a plurality of tandemly mounted packer members 28 and 29. The latter are carried on a common central mounting element 44. Said element serves as a bearing surface or sleeve which slidably engages the outer wall of conductor 19. In this embodiment, each of the respective packers includes inner and outer inflatable members such as 33 and 39, all of which are manifolded to fluid actuating conduit 41. Thus, the tandem packers can be actuated simultaneously into either their expanded or contracted state.

Under normal bitumen emulsion producing conditions, the entire well 10 will be put into operating condition by preheating the well 10, as well as by penetrating the substrate adjacent thereto with the hot stimulating

medium. In such an instance, steam is introduced to substrate 13 by way of the production segment 37. Thus, the flow of steam through conductor 19 is received from a source thereof and regulated at valve 24. A second flow of heating steam is introduced by way of well head 23 and valve 26 to the producing segment 36 of liner 17 which terminates at diverter 27.

The initial preheating or soaking phase of a producing operation can consume several weeks depending on the length of the well through the substrate, and the efficiency of the heat transfer facility.

During this soak period, hot pressurized steam will flow from all parts of liner 17 and penetrate the layer 13. In that the hot steam is under pressure it will tend to move upwardly through substrate 13, thereby progressively liquefying the bitumen, causing it to intermix with the steam condensate thereby forming a hot bitumen emulsion.

To commence the actual producing operation, the flow of stimulating steam through valve 26 and to the production end 37 of the liner 17 is discontinued. However the introduction of stimulating heat to central conductor 19 is continued such that the steam will enter the injection segment 36 of liner 17 and continue to be passed outwardly and into substrate 13.

Due to the pressure differential in liner 17 across the diverter member 27, the steam will tend not only to gravitate upwardly, but will also tend to move from the higher pressure segment 36 of the liner, toward the lower pressured production segment 37.

Referring to FIG. 3, as the bitumen is progressively melted the resulting emulsion will enter the perforations 18 thereby establishing a pattern of flow paths identified collectively as A, through tar sand layer 13. This pattern is formed by the flowing bitumen emulsion as the latter seeks the lower pressure end of the liner producing segment 37.

Accumulated bitumen emulsion within liner 17 can be removed therefrom by gravity flow, by pumping or by other suitable means. In either instance, production outflow will continue until it becomes evident from the volume produced at well head 23, and from the amount of steam produced concurrently therewith, that the thermally treated subterranean area of layer 13 has been depleted of bitumen.

To revive the bitumen flow at well head 23, it is necessary to adjust the flow path pattern A by extending the individual flow paths into areas that had been preheated but are not producing.

Again referring to FIG. 3, this adjustment is achieved by withdrawing flow diverter 27 from its initial position at location X within liner 17, and further into the producing segment 37 to a location Y, closer to well head 23.

With diverter 27 in the new position, hot stimulating fluid is again introduced through conductor 19. Pressurized steam will continue to pass outwardly into the substrate 13. However, the steam will also enter the enlarged or extended injection segment 36 of liner 17 which has been formed as the result of diverter 27 being repositioned further into segment 37.

As hot stimulating fluid continues to penetrate tar sand layer 13, it will establish new set of flow paths identified collectively as B. These paths are established in heretofore unproduced sections of the said layer as the bitumen emulsion again gravitates toward the lower pressured producing segment 37 of the liner. These new

flow paths A, will constitute not only an extension of the old flow paths, but will also result in an extension of the entire flow pattern.

In this new position of diverter 27 at Y, producing of the bitumen emulsion is continued until as herein noted, a decrease will become evident in the volume produced at the well head 23, together with greater amounts of steam being discharged concurrently therewith.

Over a period of time, the diverter 27 will be progressively moved in incremental steps toward the well head 23 until such time as the diverter has passed through the liner 17 and is at the upper limit of the tar sand layer 13.

At this point in the operation, the tar sand layer will have been completely thermally treated and consequently will have been drained of available bitumen.

Although modifications and variations of the invention can be made without departing from the spirit and scope thereof, only such limitations should be imposed as are indicated in the appended claims.

We claim:

1. Well completion for producing bitumen emulsion from a subterranean tar sand layer in which the bitumen is releasably held, which completion includes:

an elongated, perforated liner which is disposed in a wellbore, the latter being in substantial horizontal alignment with respect to the tar sand layer having an upper end, and terminating at a remote injection end,

a conductor extending longitudinally of said liner having at least one discharge port adjacent to the liner remote end, and communicated at the other end to a pressurized source of a hot stimulating fluid whereby said fluid can be conducted through said conductor and injected into the substrate adjacent to said liner,

a well head at the upper end of the respective liner and the conductor,

flow diverter means within said liner operably registered in the conductor to be moved longitudinally therealong, said flow diverter means being actuable to engage the liner walls and form an annular seal thereby to segregate the liner into discrete injection and producing segments respectively,

means for displacing said flow diverter through said liner whereby to concurrently adjust the length of the respective injection and producing segments, and a conductor positioning bracket engaging said conductor and liner respectively, to fixedly position the conductor at the liner remote injection end.

2. Well completion as defined in claim 1, wherein said means for displacing the flow diverter includes a cable means which is attached to the diverter means and extends to said well head.

3. Well completion as defined in claim 1, wherein said flow diverter means includes, a body having an axial passage extending therethrough, said conductor being registerable within said axial passage to be slidably positioned thereon, and being operable to form a fluid tight seal with the conductor wall.

4. Well completion as defined in claim 3, wherein said flow diverter includes, a plurality of longitudinally spaced apart bodies and a common sleeve supporting the respective bodies to permit sliding movement thereof along said conductor.

* * * * *

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United States Patent [19]

Fitch et al.

[11] Patent Number: 4,510,997

[45] Date of Patent: Apr. 16, 1985

[54] SOLVENT FLOODING TO RECOVER VISCOUS OILS

- [75] Inventors: John L. Fitch, Dallas; Lynn D. Mullins, De Soto, both of Tex.
 [73] Assignee: Mobil Oil Corporation, New York, N.Y.
 [21] Appl. No.: 564,814
 [22] Filed: Oct. 25, 1983

Related U.S. Application Data

- [63] Continuation of Ser. No. 308,755, Oct. 5, 1981, abandoned.
 [51] Int. Cl.: E21B 43/22
 [52] U.S. Cl.: 166/263; 166/50; 166/274
 [58] Field of Search: 166/50, 263, 268, 272, 166/274

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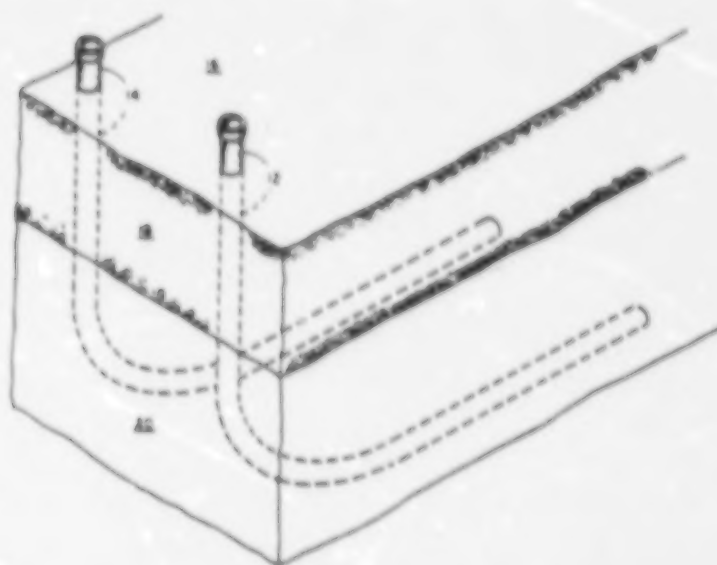
Primary Examiner—George A. Suchfield

Attorney, Agent, or Firm—A. J. McKillop, M. G. Gilman, L. O. Miller

[57] ABSTRACT

Oil may be recovered from viscous oil-containing formations including tar sand deposits by providing at least one injection well and at least one spaced-apart production well which extend downwardly from the surface and which extend to and generally horizontally through the bottom of the oil-containing formation with fluid communication of the horizontally extending portions of each well with the oil-containing formation. A predetermined amount of solvent, preferably 0.05 to 0.30 pore volume is injected into the bottom of the formation via the injection well and fluids including oil are recovered from the formation via the production well. After the desired amount of solvent has been injected into the formation, production is terminated and both the injection well and production well are shut-in to allow the formation to undergo a soak period for a variable time, preferably for a time between 2 to 30 days per foot of vertical thickness of the oil-containing formation. During the soak period, there is substantial mixing of the heavy oil and the solvent in the formation by gravity-driven convection wherein the viscosity of the heavy oil is reduced, thereby making it easier to produce. A driving fluid such as water is then injected into the formation via the injection well and oil of reduced viscosity is produced until there is an unfavorable amount of driving fluid, preferably at least 90 percent.

7 Claims, 3 Drawing Figures



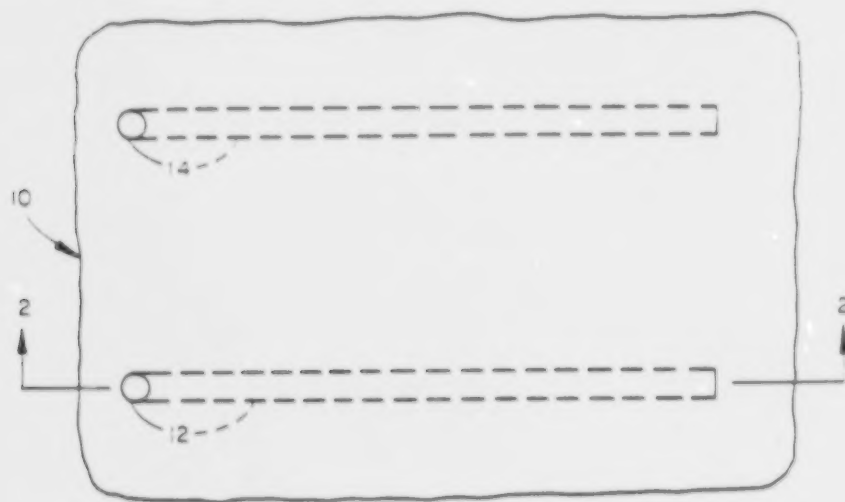


FIG. 1

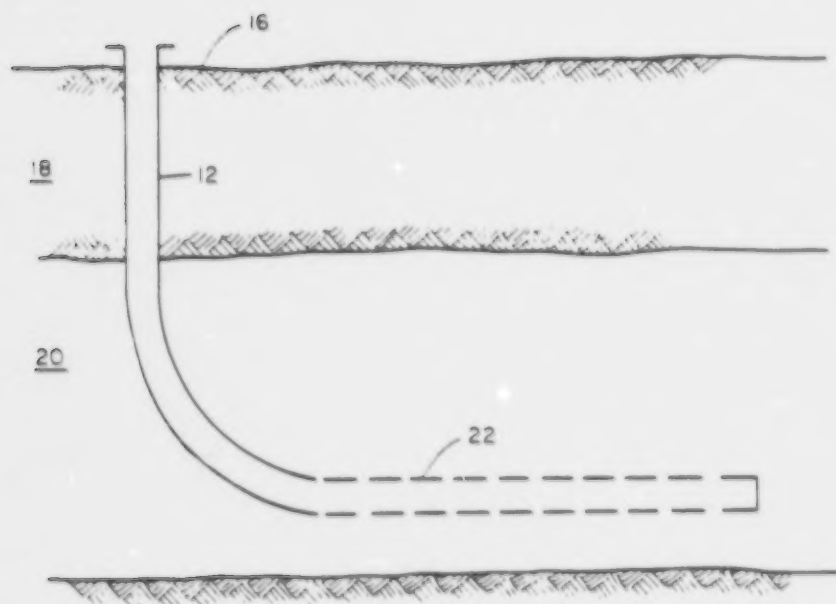


FIG. 2

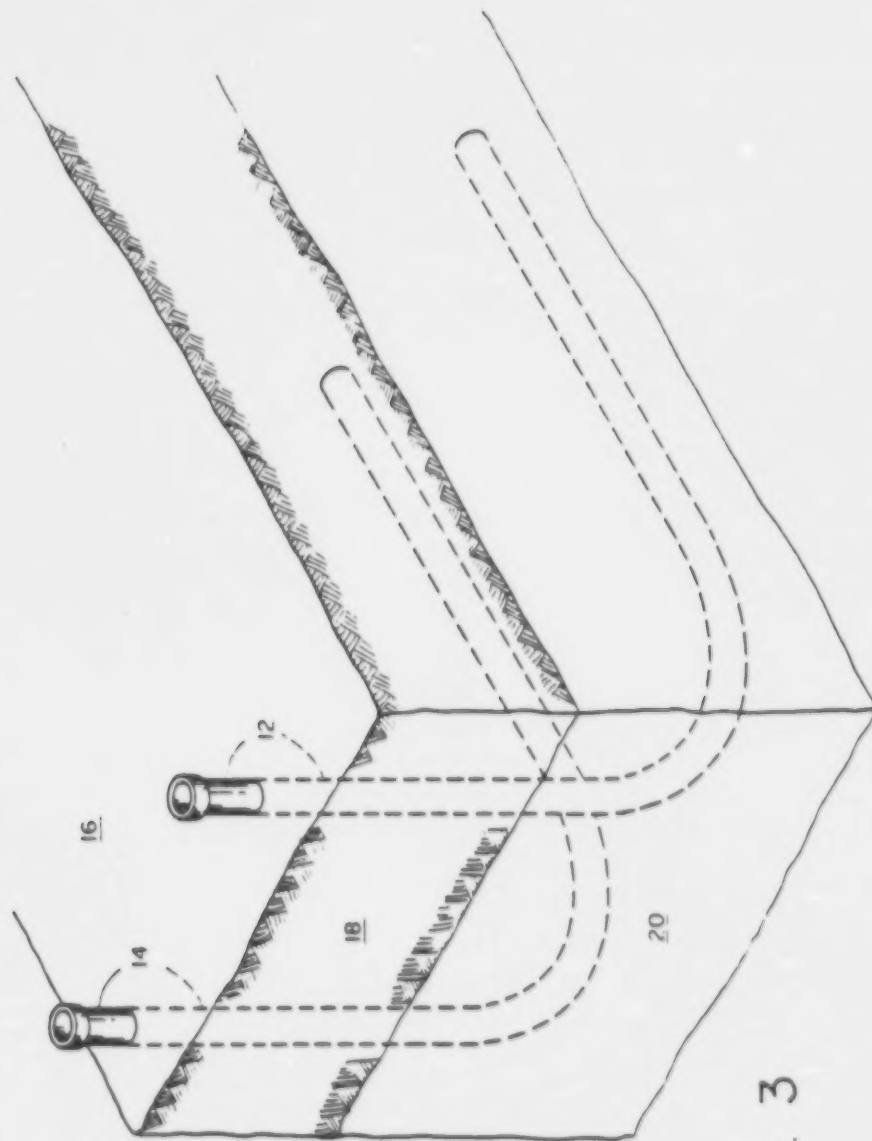


FIG. 3

SOLVENT FLOODING TO RECOVER VISCOUS OILS

This is a continuation of copending application Ser. No. 308,755 filed on Oct. 5, 1981 now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention is directed to a method of recovering oil from viscous oil-containing subsurface formations. More particularly, this invention is directed to a hydrocarbon solvent recovery method for recovering oil from subsurface formations that are penetrated by at least one injection well and one production well which extend downwardly from the surface of the earth into the bottom of the oil-containing formation and then extend horizontally through the formation.

2. Description of the Prior Art

In co-pending application filed July 21, 1981, Ser. No. 285,696, now U.S. Pat. 4,373,585, to Fitch et al., there is disclosed a method of recovering viscous oil from a viscous oil-containing formation wherein a selected solvent is injected into a fluid communication path in the lower portion of the formation intermediate at least an injection well and a production well. A hydrocarbon solvent having a density less than oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions is injected into the communication path and fluids including oil are recovered from the production well until the fluid recovered contains an unfavorable ratio of oil to solvent. The production well is shut-in and an additional quantity of the hydrocarbon solvent is injected into the fluid communication path, preferably until a total amount of between 0.05 to 0.30 pore volume has been injected. The injection well is then shut-in along with the production well to permit the formation to undergo a soak period for a variable time, preferably for a time of between 2 to 20 days per vertical thickness in feet of oil-containing formation. A driving fluid such as water is then injected into the formation via the injection well and the oil is produced until there is an unfavorable ratio of oil to driving fluid. During the fluid drive recovery phase, the injection well and production well may be completed to be in fluid communication with the entire portion of the formation to obtain a more uniform displacement of the solvent and oil mixture in the formation by the driving fluid.

In co-pending application Ser. No. 46,275, now U.S. Pat. No. 4,293,035, filed June 7, 1979, to John L. Fitch, there is disclosed a method of recovering viscous oil from the viscous oil bearing subsurface formation wherein a solvent is injected into a high mobility channel formed in the bottom of the formation intermediate an injection well and a production well. The solvent is injected until the ratio of produced oil to solvent becomes unfavorable and thereafter the injection of solvent is terminated and gas is injected into the high mobility channel to produce solvent and oil from the formation.

In U.S. Pat. No. 3,838,738 there is described a method for recovering viscous petroleum from petroleum-containing formations by first establishing a fluid communication path low in the formation. A heated fluid is then injected into the fluid communication path followed by injecting a volatile solvent such as carbon disulfide,

benzene or toluene into the preheated flow path and continuing injecting the heated fluid and recovering fluids including petroleum from the production well.

In U.S. Pat. No. 3,500,917 there is disclosed a method for recovering crude oil from an oil-bearing formation having a water-saturated zone underlying the oil-saturated zone. A mixture of an aqueous fluid which has a density greater than the density of the crude oil and a solvent having a density less than the density of the crude oil are injected into the water-saturated zone and oil is produced from the formation.

U.S. Pat. No. 4,026,358 discloses a method for recovering heavy oil from a subterranean hydrocarbon-bearing formation traversed by at least one injection well and one production well wherein a slug of hydrocarbon solvent in amounts of 0.1 to about 20 percent of the formation pure volume and having a gas dissolved therein is injected into the formation via the injection well. Thereafter, a thermal sink is created in the formation by in-situ combustion or by injecting steam. The wells are then shut-in for a predetermined time to permit the formation to undergo a soak period, after which production is continued. Optionally, after the production period, the formation may be water flooded to recover additional oil from the formation.

SUMMARY OF THE INVENTION

This invention is directed to a method of recovering viscous oil from a viscous oil-containing formation that has no significant vertical permeability barrier in the portion of the formation being produced involving at least one injection well and at least one spaced-apart production well that vertically penetrate the formation and then extend horizontally through the bottom of the formation for injection of a predetermined amount of solvent into the formation and recovery of oil from the formation. The injection well and production well are drilled into the formation extending downwardly from the earth's surface to the bottom of the oil-containing formation and then a substantial distance through the formation in a generally horizontal direction. That portion of the injection well and production well that extends horizontally through the bottom of the formation is perforated or otherwise equipped to provide fluid communication between both wells and the formation. The production well is spaced-apart from the injection well but the horizontal portion of the production well is at the same level as, and parallel to, the horizontal portion of the injection well. A predetermined amount of hydrocarbon solvent having a viscosity not greater than 1/100 the viscosity of the oil contained in the formation and a specific gravity less than the oil contained in the formation under formation conditions, is injected into the bottom of the formation via the injection well and fluids including oil are recovered from the production well. The amount of solvent injected is preferably 0.05 to 0.30 pore volume. After the desired amount of solvent has been injected into the formation, production is terminated and both the injection well and production well are shut-in to permit the formation to undergo a soak period for a variable time, preferably for a period of time between 2 to 20 days per foot of vertical thickness of the oil-containing formation. During this soak period, the light hydrocarbon solvent will tend to rise and the heavy oil will move downward in a gravity-driven convection process forming a pattern of fingers. This fingering causes an effective contact between the oil and solvent thus providing a greater volume of oil

that is reduced in viscosity thereby increasing the rate of oil recovery. Thereafter, a driving fluid such as water is injected into the injection well to displace the oil of reduced viscosity toward the production well for recovery. Production is continued until the oil recovered from the production well contains an unfavorable amount of driving fluid, preferably at least 90 percent.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic plan view of an area which overlies an oil-containing formation, and it indicates by dotted lines an injection well and a production well which extend downwardly from the surface to the bottom of the oil-containing formation.

FIG. 2 is a sectional view through the area shown in FIG. 1 and it is taken along the plane indicated by the lines 2-2 in FIG. 1 showing the manner in which the injection well and production well penetrate the formation.

FIG. 3 is an isometric view of a rectangular block of the earth showing the position of the injection well and the production well within the formation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention relates to a hydrocarbon solvent recovery method for recovering viscous oil from a viscous oil-containing subsurface formation that has no significant vertical permeability barrier in the portion of the formation to be treated utilizing injection and production wells which extend from the earth's surface downwardly into the oil-containing formation and then extend horizontally through the lower portion of the oil formation. Viscous oil is a term used to identify oil having relatively high viscosity and includes those oils referred to as tars. Such viscous oils are also referred to as heavy oils. In general, the term viscous oil is used to include those heavy oils and tars such as are commonly found in formations referred to as heavy oil or tar sands that have viscosities that are great enough to severely restrict the production of the oils from the formations in which they are found. The API gravity of such viscous oils is normally 20° API or less.

Referring to FIG. 1, a field 10 overlying an oil-containing formation is provided with an injection well 12 and a production well 14. As shown in FIGS. 2 and 3, the injection well 12 and the production well 14 extend downwardly from the earth's surface 16, through an overburden 18, into the oil-containing formation 20 and then extend horizontally through the bottom of the formation. The production well 14 is spaced apart from the injection well 12 and the horizontal portion of the production well is at the same level and parallel to the horizontal portion of the injection well. The horizontally extending portion of the injection well 12 and the production well 14 have perforations 22 providing fluid communication between that portion of each well and the lower portion of the formation 20. Although only one injection well and one production well are shown for purposes of illustration, it is understood that a plurality of alternating spaced apart injection wells and production wells may be used in our process with the number depending upon the characteristics of the oil-containing formation. The wells may be formed by conventional directional drilling means with the horizontally extending portion of each well in the bottom of the formation being within plus or minus 20° degrees of a horizontal plane.

A predetermined amount of solvent having a specific gravity less than the specific gravity of the oil contained in the formation and having a viscosity not greater than 1/100 of the viscosity of the oil contained in the formation under formation conditions is injected into the bottom of the formation via the injection well 12 and fluid including oil is recovered from the formation via production well 14. The amount of solvent injected into the formation during this step is preferably within the range of 0.05 to 0.30 pore volume. Once this amount of solvent has been injected, the injection well 12 and the production well 14 are shut-in and the formation 20 is allowed to undergo a soak period for a predetermined time, preferably for a period of time between 2 to 20 days per foot of vertical thickness of the oil-containing formation. It will be recognized by those skilled in the art of oil recovery that during this shut-in or soak period minor amounts of fluid may be injected or produced, such as for the purpose of testing, without significant detrimental effects on the process. During this soak period, the liquid hydrocarbon solvent being lighter than the oil contained in the viscous oil-containing formation, that is, having a specific gravity less than the specific gravity of the oil contained in the formation and having a viscosity not greater than 1/100 of the viscosity of the oil contained in the formation under formation conditions, will tend to flow by gravity-driven convection upward into the oil-containing formation and the heavy oil will flow by gravity-driven convection downward to form a pattern of fingers. This fingering is important in that the distribution, size and extension of these fingers will provide intimate contact between the solvent and the heavy oil allowing the two to mix more effectively, thus forming a greater volume of oil that is reduced in viscosity and which can be produced more readily. This relatively low viscosity mixture can be much more effectively displaced from the reservoir than the original heavy oil by flooding the formation with water or suitable fluid, as is well known to those skilled in the art of petroleum engineering.

Once the soak period has been completed, a driving fluid is injected into the formation 20 via the injection well 12 and oil of reduced viscosity is recovered from the production well 14. The driving fluid displaces the mobilized oil from the formation 20 into the production well 14 and production is continued until the recovered oil contains an unfavorable amount of driving fluid, preferably at least 90 percent. The driving fluid for use in our invention may be gaseous or liquid. For example, gases include light aliphatic hydrocarbons having from one to four carbon atoms, carbon dioxide and nitrogen may be used for the process of our invention. Aqueous fluids are particularly preferred driving fluids in the process of our invention. Water, brine and thickened aqueous fluids are all suitable aqueous fluids for the purpose of our invention.

The hydrocarbon solvents used in our process must have a specific gravity less than that of the oil and less than that of the brine injected or naturally present in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions. It is also highly desirable that the hydrocarbon solvent remain liquid under the temperature and pressure conditions that exist in the subsurface viscous oil-containing formation and not cause solids such as asphaltenes to precipitate from the oil in amounts sufficient to seriously plug the pores of the formation. The preferred hydrocarbon solvent is a light

crude oil. Other examples of suitable hydrocarbon solvents include light oil condensates having an API gravity greater than 30 API degrees and partially refined tar which is generally known as syncrude. It may be desirable to include in the hydrocarbon solvent up to about 10 percent of aromatic material such as aromatic refinery stock to make the solvent compatible with the oil contained in the formations and to prevent the deposition of solid or gelatinous materials such as asphaltenes therefrom.

The viscous oil-containing subsurface formation to be treated by the present hydrocarbon solvent recovery method must be one that has no significant vertical permeability barriers in that portion of the formation to be treated. This allows the solvent that is injected into the lower portion of the formation between the injection well and production well to flow upward into the formation by convection forces thus solubilizing the oil and forming a solvent-oil mixture of reduced viscosity that can be more readily produced by a fluid drive process.

In a further embodiment, the injection well and the production well may extend downwardly from the earth's surface into the bottom of the oil-containing formation with the lower portion of each well extending through the formation at a downward angle not greater than 20° relative to a horizontal plane and the lower portion of each well in fluid communication with the formation. The production well is spaced apart from the injection well and the lower portion is at the same level and parallel to the lower portion of the injection well.

By the term "pore volume" as used herein, is meant that volume of the portion of the formation underlying the well pattern employed as described in greater detail in U.S. Pat. No. 3,927,716 to Burdyn et al., the disclosure of which is incorporated by reference.

What is claimed is:

1. A method of recovering viscous oil from a subterranean viscous oil-containing formation having no significant vertical permeability barrier therein comprising the steps of:

- (a) providing at least one injection well extending downwardly from the earth's surface to the bottom of said oil-containing formation and then extending outwardly a substantial distance through said formation in a generally straight horizontal direction;
- (b) providing at least one production well extending downwardly from the earth's surface to the bottom of said oil-containing formation and then extending outwardly a substantial distance through said formation in a generally straight horizontal direction;
- (c) said production well being spaced from said injection well and the generally straight horizontal portion of said production well being generally at the

same level as, and being generally parallel to, the generally straight horizontal portion of said injection well.

- (d) said injection well and said production well being in fluid communication with the formation over the distance of each well extending through said formation in a generally straight horizontal direction;
- (e) injecting a predetermined amount of hydrocarbon solvent into the formation via said injection well, said solvent having a specific gravity less than the specific gravity of the oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions and recovering fluids including oil from the formation via said production well;
- (f) thereafter, shutting-in said injection well and said production well to permit said formation to undergo a soak period for a predetermined period of time wherein the solvent mixes with the oil in the formation by gravity-driven convection to reduce the viscosity of the oil; and
- (g) thereafter injecting a driving fluid into the formation via said injection well and recovering fluids including oil of reduced viscosity from said formation via said production well until the fluid being recovered from the production well comprises an unfavorable amount of driving fluid.

2. The method of claim 1 wherein the total amount of solvent injected during step (e) is between 0.05 and 0.30 pore volume and the soaking period during step (f) is for a period of time between 2 and 20 days per foot of vertical thickness of the oil-containing formation.

3. The method of claim 1 wherein the driving fluid injected during step (g) is a gaseous material selected from the group consisting of carbon dioxide, nitrogen or aliphatic hydrocarbons having one to four carbon atoms.

4. The method of claim 1 wherein the driving fluid injected during step (g) is water.

5. The method of claim 1 wherein said hydrocarbon solvent is selected from the group consisting of a light crude oil having an API gravity greater than 30 API degrees and a light crude oil product generally known as syncrude.

6. The method of claim 1 wherein production of fluids from the formation by the production well according to step (g) is continued until the fluid recovered contains at least 90 percent driving fluid.

7. The method of claim 1 wherein the outwardly extending straight horizontal portion of the injection well and production well is at an angle not greater than plus or minus 20 degrees relative to a horizontal plane through the formation.

* * * * *

United States Patent [19]

Wolcott, Jr.

[11] Patent Number: 4,522,260

[45] Date of Patent: Jun. 11, 1985

[54] METHOD FOR CREATING A ZONE OF INCREASED PERMEABILITY IN HYDROCARBON-CONTAINING SUBTERRANEAN FORMATION PENETRATED BY A PLURALITY OF WELLBORES

[75] Inventor: Herbert B. Wolcott, Jr., Plano, Tex.

[73] Assignee: Atlantic Richfield Company, Los Angeles, Calif.

[21] Appl. No.: 583,065

[22] Filed: Feb. 23, 1984

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 366,510, Apr. 8, 1982, Pat. No. 4,446,918

[51] Int. Cl.³ E21B 43/24; E21B 43/247; E21B 43/30

[52] U.S. Cl. 166/245; 166/50; 166/248; 166/259; 166/272; 166/299

[58] Field of Search 166/50, 245, 259, 299, 166/248, 272, 299/2, 13; 48/DIG. 6

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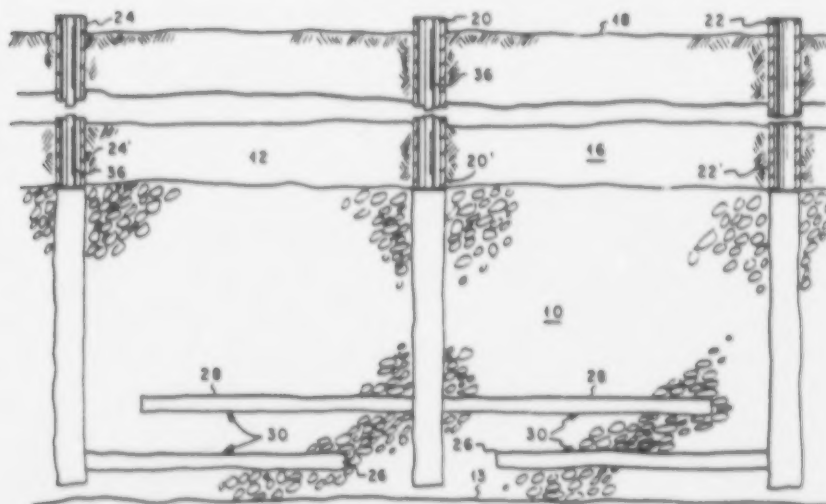
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Primary Examiner—George A. Suchfield
Attorney, Agent, or Firm—F. Lindsey Scott

[57] ABSTRACT

A method for creating a zone of increased permeability in a subterranean hydrocarbon-containing formation penetrated by a plurality of wellbores by penetrating the formation with a first wellbore; positioning a plurality of other wellbores about the first wellbore with each of the other wellbores having at least one substantially horizontal borehole extending therefrom into the vicinity of the first wellbore; extending a plurality of substantially horizontal boreholes from the first wellbore into the vicinity of the other wellbores; positioning explosive charges in at least a portion of the boreholes and detonating the explosive charges to produce a rubble zone between the first wellbore and the other wellbores.

13 Claims, 2 Drawing Figures



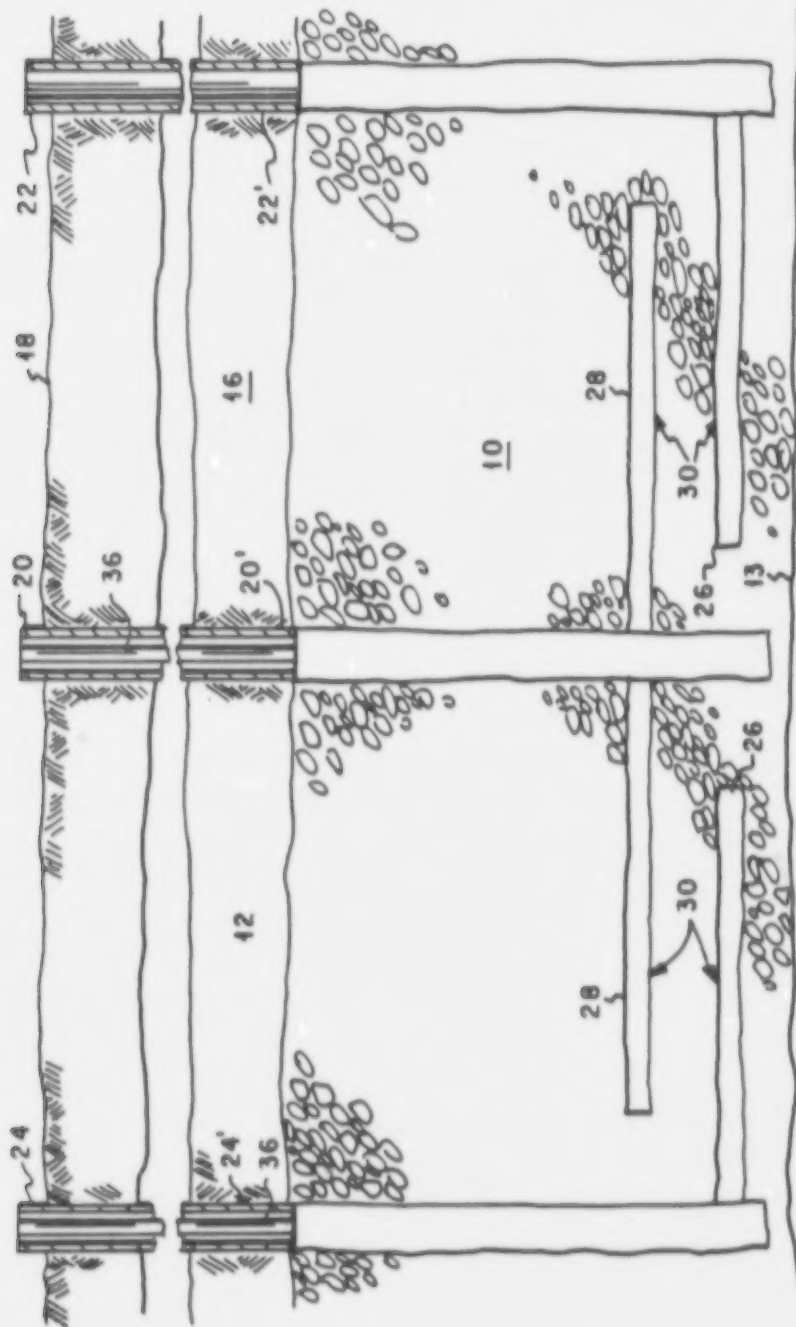


FIG. 1

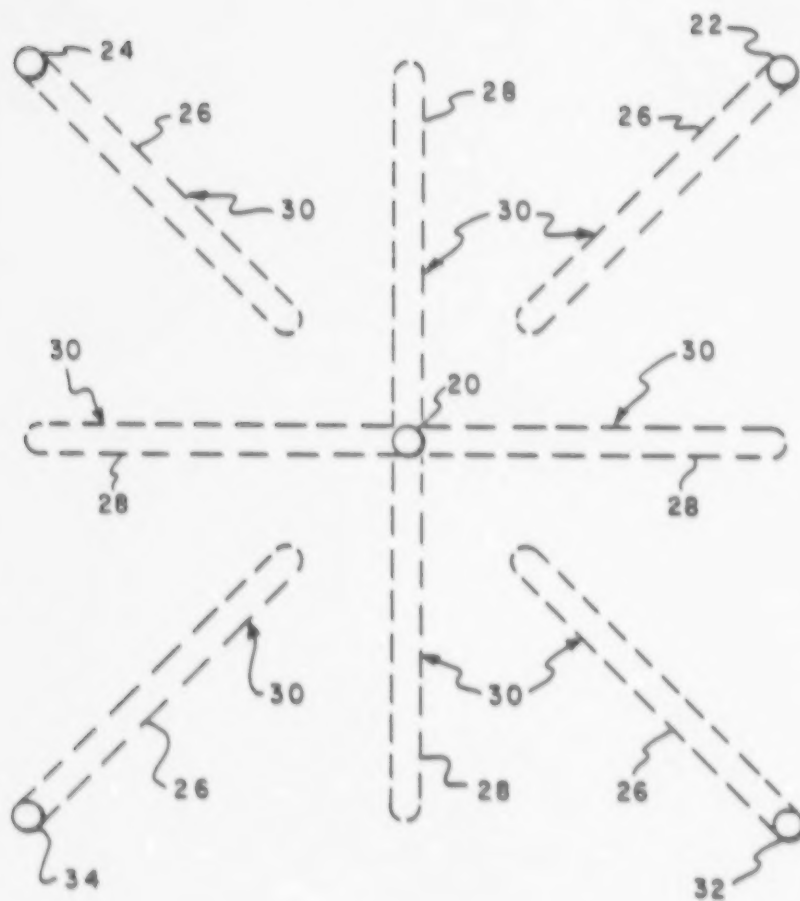


FIG. 2

METHOD FOR CREATING A ZONE OF INCREASED PERMEABILITY IN HYDROCARBON-CONTAINING SUBTERRANEAN FORMATION PENETRATED BY A PLURALITY OF WELLBORES

This application is a continuation in part of my earlier filed U.S. patent application, Ser. No. 366,310, entitled "Method For Initiating Combustion In A Subterranean Carbonaceous Deposit" filed Apr. 8, 1982, now U.S. Pat. No. 4,446,918.

This invention relates to a method for creating a zone of increased permeability in a subterranean hydrocarbon-containing formation.

This invention further relates to an improvement in enhanced recovery methods for the recovery of hydrocarbons from hydrocarbon-containing formations which have poor drainage of hydrocarbons into wells penetrating such subterranean formations.

In recent years, there has been an increased interest in the recovery of hydrocarbons from formations which have previously been considered unsuitable for the production of hydrocarbon materials. Some such formations are tar sands, heavy oil-containing formations, oil shales and tight gas reservoirs. Such formations are known to contain substantial quantities of valuable hydrocarbon materials. However, these materials are recoverable from such formations only with considerable difficulty. In many instances, the hydrocarbon materials are highly viscous and do not flow readily from the formations. Various enhanced recovery methods have been used to reduce the viscosity of such materials by heating the hydrocarbons, mixing viscosity-reducing materials with the hydrocarbons, diluting the hydrocarbons with solvents and the like. Such methods are designed to reduce the viscosity of hydrocarbon materials so that they will flow from the hydrocarbon-containing formation into wellbores, cavities in the formation or the like for recovery by pumping to the surface of the like. Many such methods are known to those skilled in the art.

All such methods require that sufficient permeability be present in the formation so that the enhanced recovery methods can be practiced. In other words, contacting the heavy hydrocarbon materials by solvents, steam, hot water or the like requires that sufficient permeability be present in the formation so that these materials can be brought into contact with the hydrocarbon materials in the formation and so that the hydrocarbons can drain from the formation. Other methods such as electric heating and the like also require that the formation have sufficient permeability so that the hydrocarbon materials can flow to a zone where they can be collected and recovered.

Many of the formations which contain such heavy hydrocarbon materials have relatively low to almost no permeability in their natural state. As a result, it is very difficult to recover hydrocarbons from such formations using enhanced recovery methods. Various alternatives to the use of conventional enhanced recovery methods in such formations have been proposed such as oil mining, tunneling, explosive fracturing with nuclear devices, and the like. Many of these approaches are directed to attempts to create zones of permeability in which enhanced recovery processes can be practiced. A prime requisite of any such method for creating a zone

of increased permeability in such formations is that it must be economical and reliable.

According to the present invention, zones of increased permeability are created between wellbores penetrating a hydrocarbon-containing subterranean formation by:

- (a) penetrating the formation with a first wellbore;
- (b) positioning a plurality of other wellbores about the first wellbore, each of the other wellbores having at least one substantially horizontal borehole extending therefrom into the vicinity of the first wellbore;
- (c) extending a plurality of substantially horizontal boreholes from the first wellbore into the vicinity of the other wellbores;
- (d) positioning explosive charges in at least a portion of the boreholes; and,
- (e) detonating the explosive charges to produce a rubblized zone between the first wellbore and the other wellbores.

A variety of well patterns can be used in the practice of the method of the present invention.

FIG. 1 is a schematic diagram of an embodiment of the process of the present invention wherein three wellbores are used; and,

FIG. 2 is a top view of a five well pattern, indicating the positioning of the boreholes used in an embodiment of the method of the present invention.

In the discussion of the Figures, the same numbers will be used to refer to the same or similar components throughout.

In FIG. 1 a subterranean hydrocarbon-containing formation 10 is shown an overburden 16. Formation 10 is penetrated by a first wellbore 20, a second wellbore 22 and a third wellbore 24 from the surface 18. Wellbores 20, 22, and 24 as shown extend to near the bottom 13 of formation 10 and are cased with casings 20', 22', and 24', respectively, to the top 12 of formation 10. Boreholes 26 extend substantially horizontally outwardly from wellbore 20 into the vicinity of wellbores 22 and 24. Boreholes 28 extend substantially horizontally from wellbores 22 and 24 into the vicinity of wellbore 20. Explosives are conveniently positioned in either boreholes 26 or 28 at points indicated by arrows 30. Explosives need not be positioned in both boreholes 26 and 28 unless required, but it is desirable that the material between boreholes 26 and 28 be rubblized upon detonation of the explosives, so that a rubblized zone of increased permeability is positioned between wellbore 22 and wellbore 20 and wellbore 20 and wellbore 24.

FIG. 2 is a top view of a five well pattern including boreholes positioned for the practice of the present invention. Additional wellbores 32 and 34 are positioned as shown. Explosives may be positioned in any or all of the boreholes as required for the efficient rubblization of the zone between the boreholes. Suitable locations for the explosives are shown by arrows 30.

The drilling of boreholes 26 and 28 is readily accomplished by means known to those skilled in the art by drainhole drilling techniques using vertical whipstock settings so that the boreholes are drilled at a common level from each well or at least from a rear common level in each well. Desirably, boreholes 26 and 28 are substantially horizontal or in the event of formations which are not horizontal, generally parallel to the plane of the formation. By the use of explosives in boreholes 26 and 28, a zone of increased permeability is created between the wellbores by rubblizing portions of forma-

tion 10 between boreholes 26 and 28. The void space required in a rubblelized zone for increased permeability is available in the form of the space comprising boreholes 26 and 28. The space comprising the boreholes permits the formation of a rubble zone which is not compacted and which permits the flow of liquid or gaseous materials freely through the rubblelized zone.

The explosives used are desirably conventional explosives which may be positioned in boreholes 26 and 28 by a variety of techniques known to those skilled in the art. For instance, the explosives used could be conventional explosives packed into a flexible plastic pipe which is then inserted into a borehole to position the explosive at the desired location.

The recovery of hydrocarbon materials from such formations may then be accomplished by a variety of enhanced recovery methods. These methods comprise techniques such as electric heating, steam injection, hot water injection, in-situ combustion, solvent extraction, and the like.

In the use of electric heating, an electric current is used to heat at least a portion of the formation so that the hydrocarbons contained in the formation have a reduced viscosity and are more readily recovered from the formation. In the use of steam, steam or superheated steam may be injected alone or in combination with other materials to reduce the viscosity of hydrocarbons contained in a subterranean formation and in some instances as a driving fluid to cause the hydrocarbons to move toward a recovery well. Similarly, hot water has been used to enhance the recovery of hydrocarbons from subterranean formations. In-situ combustion has been used to enhance the recovery of hydrocarbons from such formations but unlike the use of in-situ combustion for the recovery of gasification products from coal and carbonaceous deposits, such in-situ combustion processes are generally designed to result in the use of combustion gases produced in-situ to reduce the viscosity of the remaining hydrocarbon materials in the formation to facilitate the recovery of such hydrocarbon materials from the formation. Gases from such in-situ combustion generally contain carbon oxides and may contain minor amounts of hydrogen and light hydrocarbon materials. Such gases are known to reduce the viscosity of heavy hydrocarbons and the thermal energy introduced into the formation by the in-situ combustion also tends to result in a reduction in the viscosity of such hydrocarbons, thus facilitating their recovery from the formation. Solvent extraction generally involves the injection of a solvent for the heavy hydrocarbons so that the heavy hydrocarbons are recovered as a solution of the solvent and heavy hydrocarbons.

Various such enhanced recovery methods are known to those skilled in the art and need not be discussed further. Most such methods require that the formation from which the hydrocarbons are to be recovered have sufficient permeability so that the enhanced recovery method materials may pass through or into the formation or sufficient permeability so that the hydrocarbon products may drain from the formation into a recovery well or the like. The practice of these methods is improved by the creation of a zone of increased permeability between wellbores penetrating such subterranean hydrocarbon containing formations. According to the method of the present invention, such a zone of improved permeability is readily created. Clearly a variety of well patterns could be used. Similarly, it may not be necessary in all instances that explosives be positioned

in all boreholes. In other words, in some instances, if the formation is sufficiently friable and otherwise suitable, a zone of increased permeability may be created between the wellbore in a given pattern without the use of explosives in all boreholes. It may be desirable in some instances that additional boreholes be drilled to create additional volume to result in increased permeability in the rubblelized zone, i.e. the zone of increased permeability.

Various advantages are achieved by the practice of the method of the present invention as follows:

- (a) a rubble zone (zone of increased permeability) of limited vertical extent and wide areal extent can be created;
- (b) expansion room for the formation solids is provided by the boreholes and the porosity of the rubblelized zone should be nearly equal to the volume of the boreholes;
- (c) substantial quantities of explosives can conveniently be positioned in the formation in the boreholes;
- (d) the expansion room provided by the boreholes will tend to reduce compaction of formation solids and loss of any natural permeability which might be present during the enhanced recovery processes;
- (e) the vertical height and areal extent of the rubblelized zone can be controlled which is an important consideration in situations where the formation might be damaged by breaking into gas caps or water zones;
- (f) a rubblelized zone of wide areal extent could provide sufficient drainage area for the successful production of light gas reservoirs and heavy oil reservoirs;
- (g) all work is done from the surface, i.e., no mining is required;
- (h) existing wells can be used; and
- (i) conventional explosives can be used.

The practice of enhanced recovery methods is considered to be known to those skilled in the art and it is not considered necessary to discuss the use of such methods in detail. In general, in such methods, a fluid which may or may not be heated is injected into a subterranean formation to improve the recovery of hydrocarbon materials from the formation. Tubing 36 has been shown in wellbores 20 and 24 to indicate that tubing can be used in the wellbores for the recovery of hydrocarbons from formation 10. The tubing in many instances will extend to near the bottom of the wellbore as will the casing in the wellbore, i.e., casings 20', 22', 24' as shown in wells 20, 22, 24, respectively. In many instances, the tubing and/or casing may be positioned to a desired depth after the formation of the rubblelized zone and the like. The specific method by which the casing is positioned to a desired depth and by which the tubing is positioned to a desired depth are highly dependent upon the particular type of enhanced recovery chosen and will not be discussed in detail. Clearly, if necessary, wells 20, 22, and 24 could be re-drilled to a desired depth through a rubblelized zone after formation of the rubblelized zone. Such techniques are well known to those skilled in the art and need not be discussed in detail.

Having thus described the present invention by reference to certain of its preferred embodiments, it is noted that the embodiments described are illustrative rather than limiting in nature and that many variations and

modifications are possible within the scope of the present invention. Many such variations and modifications may be considered obvious and desirable by those skilled in the art upon a review of the foregoing description of preferred embodiments.

Having thus described the invention, I claim:

1. A method for creating a zone of increased permeability in a subterranean hydrocarbon-containing formation selected from the group consisting of tar sands, heavy oil-containing formations, oil shales and tight gas reservoirs penetrated by a plurality of wellbores, said method consisting essentially of:

- (a) penetrating said formation with a first wellbore;
- (b) positioning a plurality of other wellbores about said first wellbore, each of said other wellbores having at least one substantially horizontal borehole extending therefrom into the vicinity of said first wellbore;
- (c) extending a plurality of substantially horizontal boreholes from said first wellbore into the vicinity of said other wellbores;
- (d) positioning explosive charges in at least a portion of said boreholes; and,
- (e) detonating the explosive charges to produce a rubble zone between said first wellbore and said other wellbores.

2. The method of claim 1 wherein said formation is a heavy oil-containing formation.

3. The method of claim 1 wherein said formation is an oil shale formation.

4. The method of claim 1 wherein said formation is a tight gas reservoir.

5. The method of claim 1 wherein said formation is a tar sand formation.

6. The method of claim 1 wherein said hydrocarbons are recovered from said formation by an enhanced recovery method.

7. The method of claim 6 wherein said hydrocarbons are recovered from said formation by a recovery

method selected from the group consisting of electric heating, steam injection, hot water injection, in-situ combustion and solvent extraction.

8. In a method for producing hydrocarbons from a hydrocarbon-containing subterranean formation selected from the group consisting of tar sands, heavy oil-containing formations, oil shales and tight gas reservoirs penetrated by a plurality of wellbores by an enhanced recovery process, an improvement comprising creating a zone of increased permeability in said formation by:

- (a) penetrating said formation with a first wellbore;
- (b) positioning a plurality of other wellbores about said first wellbore, each of said other wellbores having at least one substantially horizontal borehole extending therefrom into the vicinity of said first wellbore;
- (c) extending a plurality of substantially horizontal boreholes from said first wellbore into the vicinity of said other wellbores;
- (d) positioning explosive charges in at least a portion of said boreholes; and,
- (e) detonating the explosive charges to produce a rubble zone between said first wellbore and said other wellbores.

9. The method of claim 8 wherein said formation is a heavy oil-containing formation.

10. The method of claim 8 wherein said formation is an oil shale formation.

11. The method of claim 8 wherein said formation is a tight gas reservoir.

12. The method of claim 8 wherein said formation is a tar sand formation.

13. The method of claim 8 wherein said enhanced recovery method is selected from the group consisting of electric heating, steam injection, hot water injection, in-situ combustion and solvent extraction.

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010643

United States Patent [19]

Dismukes

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[45] Date of Patent: **Jun. 18, 1985**

[54] THERMAL OIL RECOVERY METHOD

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[21] Appl. No.: **946,018**

[22] Filed: **Oct. 27, 1983**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 933,272, Aug. 14, 1978, abandoned, which is a continuation-in-part of Ser. No. 829,810, Dec. 23, 1977, abandoned.

[51] Int. Cl.³ **E21B 43/24; E21B 36/00**

[52] U.S. Cl. **166/302; 166/57;
166/77**

[58] Field of Search **166/230, 173, 77, 302,
166/57, 173/94, 92, 104, 422, 107, 61; 299/34,
13**

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Primary Examiner—Stephen J. Novosad

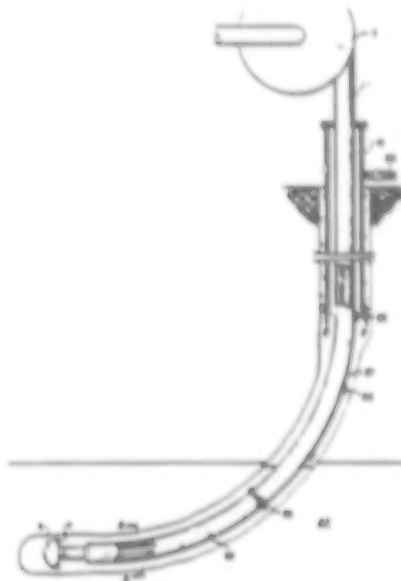
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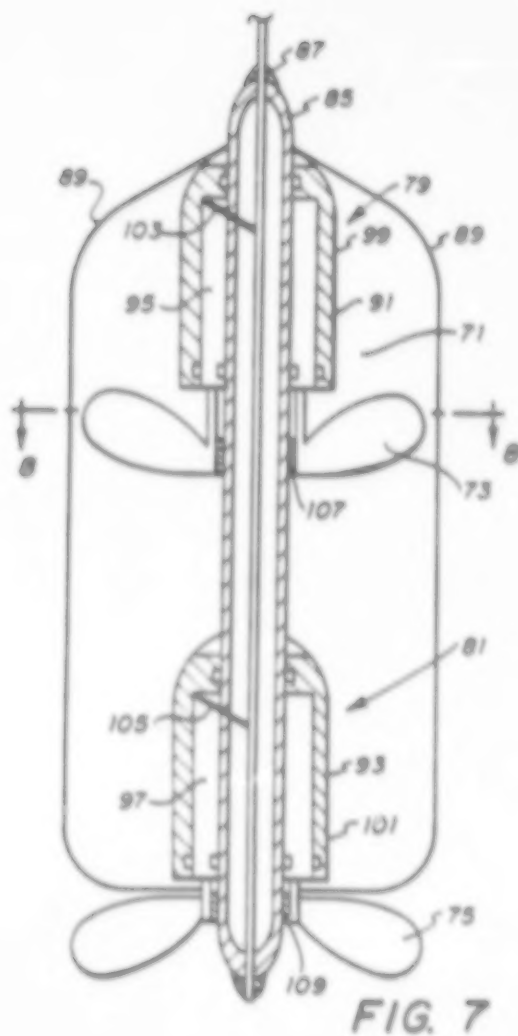
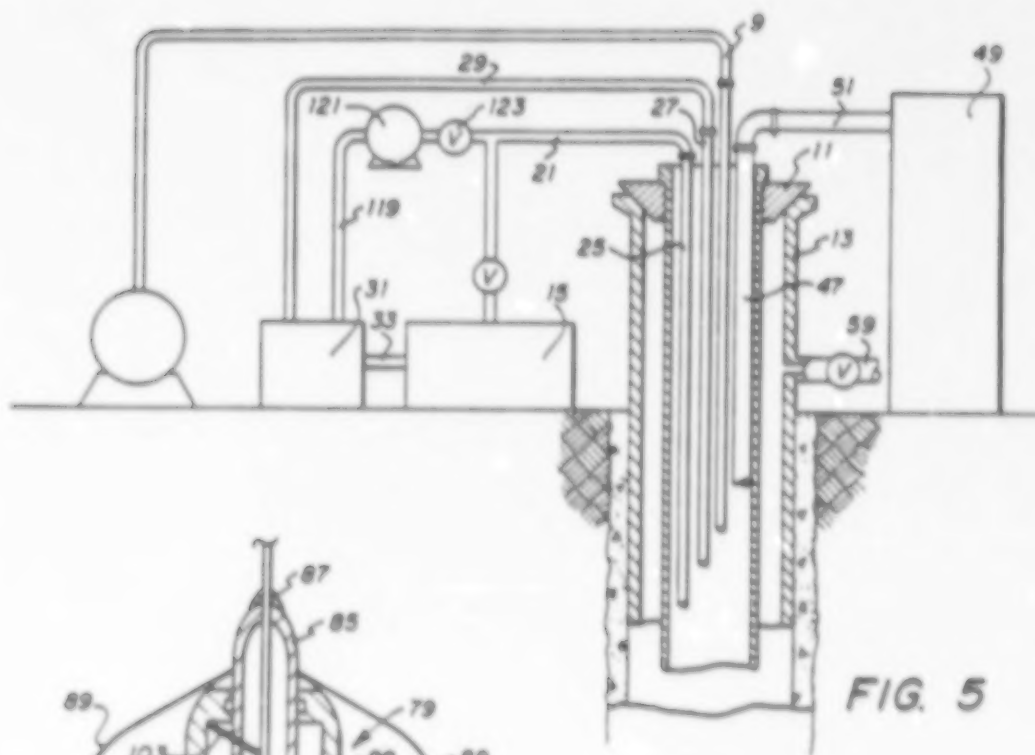
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Faulconer

[57] ABSTRACT

A system for recovery of oil, particularly viscous oil, from subsurface formations penetrated by highly deviated or horizontal bore holes by circulating there-through a heated fluid. The heated fluid is circulated through a flexible conduit which is pulled into the bore hole by thrust generating means at the forward end thereof. Power to operate the thrust generating means is also conducted through the conduit. Produced oil is returned via the conduit.

29 Claims, 12 Drawing Figures





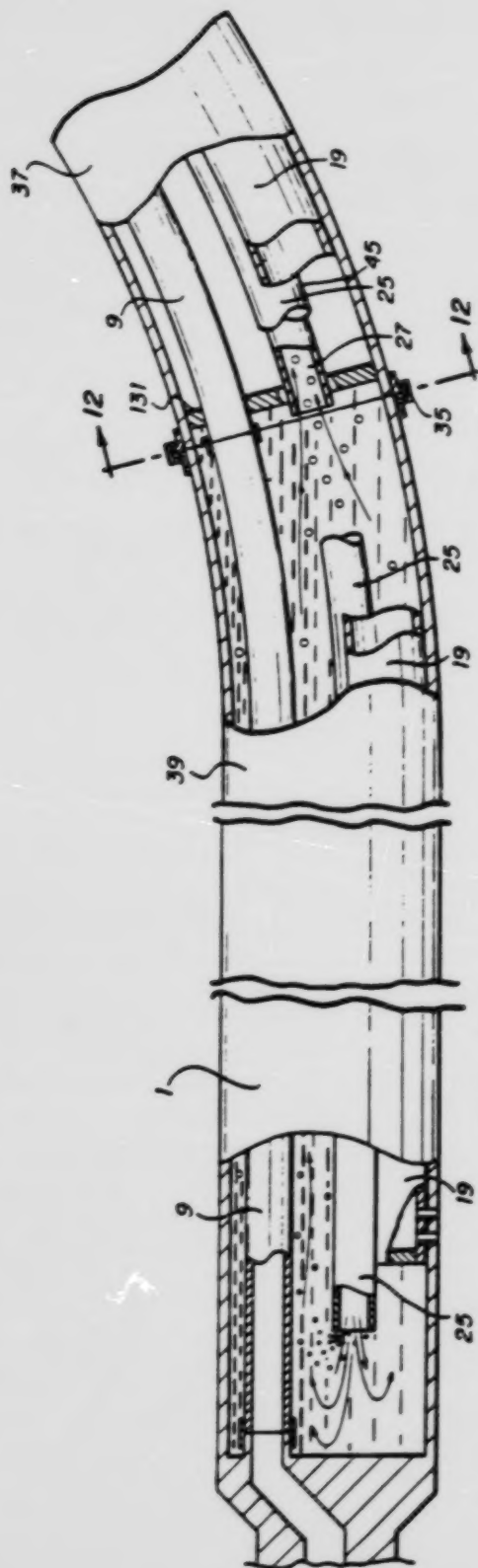


FIG. 11

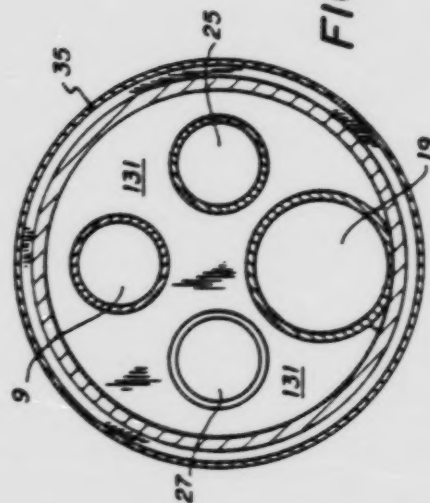


FIG. 12

THERMAL OIL RECOVERY METHOD

RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 933,272, filed Aug. 14, 1978, now abandoned and is directed to the nonelected subject matter disclosed and claimed therein. Application Ser. No. 933,272 in turn was a continuation-in-part of application Ser. No. 829,810, filed Dec. 23, 1977, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates generally to the recovery of viscous petroleum from viscous petroleum containing formations. Major deposits containing such petroleum deposits are located in western Canada, United States and in Venezuela. The depths of such deposits range from surface outcroppings to several thousand feet. This invention is directed to the recovery of petroleum from deposits located where surface mining techniques are impractical, and the injection of steam into the formation via a multiplicity of closely spaced wells is uneconomical or impractical.

To recover petroleum from such deposits proposals have been made to drill bore holes in a generally horizontal direction within the viscous petroleum containing formation. Such horizontal bores may be drilled either by deviating a conventional well bore or by excavating a mined shaft to the desired depth, lowering drilling equipment therein, and drilling the horizontal shafts therefrom. Systems of the latter type are disclosed in U.S. Pat. No. 3,994,340 to Donald J. Anderson et al and in U.S. Pat. No. 4,020,901 to Peter Pizio et al. Such systems are expensive to install especially where the depth of the formation exceeds a few hundred feet. With highly deviated bore holes, and especially where the terminal portion of such bore holes extends for substantial distances in a generally horizontal direction, the problem of introducing equipment for circulating steam and for recovering produced petroleum has not been solved to my knowledge, since the forces of gravity do not provide advancing force in the horizontal bore. Additionally, portions of horizontal well bores often cave in or slough. Therefore, when introducing equipment for heating and producing petroleum therefrom it is very desirable to circulate liquid through such equipment and around the space between the equipment and the bore hole wall to remove any material sloughed off the bore hole walls.

Many systems have been devised for injecting steam directly into the formation via closely spaced wells using either steam drive or the "huff and puff" method. Such steam must be at a pressure higher than reservoir pressure so that it can be injected into the formation. As is well known, the more closely steam approaches the critical condition the less its latent heat. This is the amount of heat required to convert liquid water to vapor and also it is the amount of heat given up when the steam condenses. It is the heat of condensation which provides the principal heat energy serving to raise the temperature of a petroleum reservoir.

For example, steam at 300 pounds per square inch and at a temperature of 417° F. has a latent heat value of 809 BTU per pound. At a pressure of 1500 pounds per square inch and a temperature of 596° F. the latent heat is only 556 BTU per pound.

In order to efficiently and economically heat a reservoir at substantial depth, steam at a pressure well below

the reservoir pressure at such depth should be used to effectively heat the petroleum sands. Therefore, for the treatment of such petroleum reservoirs by heating with steam at pressure below reservoir pressures, the steam must be circulated in a closed loop system. The rate of heat flow from a conduit filled with a heated fluid to a surrounding oil reservoir is controlled by the coefficient of heat transfer from the conduit wall which is measured in BTU per hour per square foot per degree Fahrenheit temperature difference. A number of factors control an overall coefficient but one which concerns this invention is the kind of insulation surrounding the conduit and its thickness. A conduit surrounded with thick, efficient insulation will transfer heat rather slowly while thin, or no, insulation permits more rapid heat flow. Thus, in a reservoir penetrated by a bore hole containing a steam-filled conduit, a selected portion of the reservoir may be heated preferentially if the conduit in that portion has a high coefficient of heat transfer by comparison with other, more effectively, insulated parts of the conduit. The portion of the conduit extending from the surface to the petroleum containing reservoir should have a low coefficient of heat transfer.

BRIEF DESCRIPTION OF THE INVENTION

The present invention is directed to the provision of a system for recovering viscous petroleum from a formation containing such petroleum via a generally horizontal well bore, such as the terminal portion of a deviated well, by circulating steam therethrough. The invention is especially useful in situations where the petroleum is contained in a reservoir wherein, because of the viscosity of the petroleum under reservoir conditions and in view of the permeability of the reservoir, the reservoir pressure is insufficient to cause the petroleum to flow into a well bore drilled therein at a rate sufficient for economic recovery. By heating the reservoir, the viscosity of the petroleum contained therein will be lowered thus increasing the rate at which the petroleum will drain into or be driven by reservoir pressure into a well bore.

A flexible conduit, capable of conforming to the curvature of the bore hole, carries tubular members providing for closed loop circulation of steam to and return of condensate from the vicinity of the terminal end of the conduit. Means are provided at the terminal end of the conduit for generating forward thrust to render the conduit self-advancing. The conduit conducts the power required to operate the thrust generating means. The conduit also includes a return flow path for produced viscous oil.

Desirably also the conduit provides a path for the introduction of a liquid, such as drilling fluid, for discharge from the terminal end and return circulation around the annulus to remove any sloughed material from the bore hole as the conduit is introduced into the well bore. This circulating liquid under sufficient pressure and volume may provide the necessary power to operate the thrust generating means. Alternatively, the conduit may include or carry conductors for electrical power.

Desirably also the conduit is so constructed that it will be substantially neutrally buoyant in the liquid filling the bore hole so that minimal force will be required for its advance and so that there will be minimal contact between the conduit and the bore hole walls, especially in the non-vertical portions of the well bore.

The term "neutrally buoyant" as used herein means that the conduit when fully immersed in the liquid will weigh not more than 30 percent of its air weight and that a downward force not to exceed 30 percent of its weight in air will completely immerse it.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side view, partly in section and partly schematic of a well bore traversing a horizontal petroleum formation with the conduit of the invention in place.

FIG. 2 is a cross-sectional view of the conduit taken on line 2—2 of FIG. 1.

FIG. 3 is a cross-sectional view of the conduit taken on line 3—3 of FIG. 1.

FIG. 4 is a detailed view of the terminal and of the conduit of FIG. 1 and the hydraulic power head form of thrust generator.

FIG. 5 is a side view, partly in section and partly schematic, of the upper end of the conduit, showing it hung in place on the top of the well casing and connected to the flow lines for the various treating and produced fluids.

FIG. 6 is a detailed view of an alternate form of the hydraulic power head form of thrust generator for use when the produced petroleum is returned to the surface via the drilling fluid conduit instead of a separate flow line.

FIG. 7 is a side view, partly in section and partly schematic, of an electrically powered form of thrust generator for a form of conduit of this invention.

FIG. 8 is a sectional view along the line 8—8 of FIG. 7.

FIG. 9 is a cross-sectional view of an alternate form of conduit for use with an electric powered form of thrust generator.

FIG. 10 is a partial bottom view, partly in section and partly schematic, of an alternative form of conduit wherein the steam introduced is circulated through a closed loop of tubing within the conduit.

FIG. 11 is a side view, partly in section, of an alternate form for the conduit of FIG. 1.

FIG. 12 is a cross-sectional view of the conduit of FIG. 11 along the line 12—12 of FIG. 11.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings, FIG. 1 illustrates the manner in which the flexible conduit is positioned in a bore hole previously drilled in such a manner that its terminal portion penetrates the viscous petroleum containing formation for a substantial distance in a direction generally parallel to the bedding plane of the formation. Since the various earth formations usually are generally horizontal, the terminal portion of the bore hole will also be generally horizontal. A preferred method for drilling a horizontal extension to a bore hole is disclosed in my co-pending application Ser. No. 304,098 filed Sept. 21, 1981.

The flexible conduit 1 is mounted upon a reel 3 and the terminal end carrying the thrust generating means 5 is introduced into the top of the bore hole and the reel unwound to introduce the conduit. In the vertical portion of the well bore, the weight of the conduit is sufficient to cause it to advance as the reel is unwound. The well bore is filled with a drilling fluid to balance the formation pressure and where the conduit is so constructed as to be substantially neutrally buoyant in such

a drilling fluid, a weight may be used to enhance the effect of gravity in insuring the descent of the leading end of the conduit as the reel is unwound. For example, a length of steel pipe or a drill collar surrounding the conduit and supported by ears projecting therefrom may provide the necessary mass. When descent of the weight slows, it may be pulled from the well by an attached sand line. As the conduit approaches the more horizontal portions of the well bore, the forces of gravity are no longer effective in insuring the smooth advance of the conduit and the thrust generator takes over as the principal force for advancing the conduit.

As shown in FIG. 1, thrust is generated by the exit of liquid through rearwardly facing jet nozzles 7 in the power head 5 at the terminal end of the conduit. This drilling fluid is introduced under high pressure through the axis of the reel into the other end of the flexible conduit. The drilling fluid passes through an inner conduit 9 (see FIGS. 2 and 4) to the power head from whence it exits through nozzles 7.

After the conduit has been introduced into the well bore to the desired position, the upper end is disconnected from the reel and hung in hanger 11 (see FIG. 5) at the upper end of well casing 13. The reel may then be removed from the vicinity of the well head and suitable connections made for interconnecting the steam generator 15, the condensate return line 29, and the production flow line 31 to the corresponding conduits in the flexible conduit, as shown in FIG. 5.

As shown in FIG. 5 with the conduit positioned in the well and connected to steam generator 15 by flow line 21, valve 23 may be opened and steam at elevated pressure and temperature will flow from flow line 21 into flow line 25 in conduit 1 to the terminal end of the conduit. During the passage of the steam through the conduit it will give up much of its heat to the formation and the resulting condensate will return to the upper end of the conduit through flow line 27 in the conduit. Desirably, the returning condensate will be returned to the steam generator via flow line 29, treater 31 and line 33 for revaporization.

The conduit is made from low density, flexible materials. The average density of the conduit may be varied and controlled by fillers such as organic or inorganic microballoons 20 to provide low density and resistance to crushing. The outer wall of the conduit may be made from a tough plastic reinforced with woven glass, steel or carbon fibers to give the conduit tensile strength so that it may be pulled into and out from the well bore and so that it will resist crushing. Since it will be exposed to elevated temperatures, the plastic must retain its strength at such temperatures. Suitable plastics for use at temperatures of from 350° F. to as high as 525° F. include Teflon, Nylon-Type 6-12, polyamides and polyimides and various polyesters.

Similar materials may be used to construct the various tubular members for conducting steam, condensate, drilling mud and produced petroleum.

As shown in FIGS. 1-3, the conduit is constructed in two sections joined together, as by end flanges 35. Tubular member 25 for introducing the steam, terminates at the lower end of the upper section 37 of the conduit and the hot steam discharged from member 25 completely fills the hollow portion of the annular space of lower conduit section 39. Desirably the lengths of the two sections are designed so that the junction therebetween is in the vicinity of the point where bore hole 41 enters the petroleum containing formation 43. To mini-

mize the loss of heat during the passage of the hot steam from generator 15 to lower conduit section 39, tubular member 25 desirably is wrapped with insulating material 45, whose thickness may be varied to control heat loss.

Production tubing 19 extends from the vicinity of the terminal end of conduit 1 to the surface where it is connected to product storage tank 49 via flow line 51. In lower conduit section 39 the production tubing is bonded to the lower side of the conduit by a suitable cementing material 53 and the conduit wall and tubing 19 are perforated by holes 56 to allow flow of oil released from the formation by the heat to enter the tubing.

Since this oil is at relatively low pressure, artificial lift means are generally required to raise the oil to the surface. As shown, a series of gas lift valves are provided along the side wall of the upper portion of conduit 37, in communication with conduit 19 via openings 57 in the walls of the conduit and the tubing. Gas under pressure introduced through flow line 59 actuates the gas lift valves and raises the produced oil to the surface. The gas lift valves are fastened to the conduit by metal straps 61 as the conduit is lowered in the well bore. Other artificial lift means may be employed to raise the petroleum produced to the earth's surface.

The details of the terminal end of the conduit and the hydraulic power head are shown in FIG. 4. Fitting 63 to which the conduit is attached is provided with a passage 65 for the flow of high pressure drilling liquid for discharge from jet nozzles 7 to generate the desired forward thrust. After the conduit has reached the desired position in the well bore, the flow of drilling liquid is terminated. Ball valve 67 prevents the flow of produced oil into line 9.

In some cases it may be feasible to dispense with production tubing string 19 and produce the liberated petroleum through tubing string 9 after it has served its function as the conduit for drilling liquid to actuate power head 5. In such situations the ball valve to prevent back flow is eliminated as shown in FIG. 6. Operation in this manner is particularly useful where formation solids are not produced.

In another embodiment of the present invention shown in FIGS. 7 and 8 an electrical power means, located at the terminal end of the conduit, drives one or more marine screw propellers, 73-75, to advance the apparatus in the bore hole. Electric power from the surface is delivered by conductors 77 (see FIG. 9) in the conduit to the electrically powered thrust generator. Preferably, two electric motors 79-81 turn the two marine screw propellers in opposite directions in the well liquid to tug the conduit forward. Use of counter-rotating propellers eliminates or substantially eliminates torque build up in a highly flexible conduit which could cause kinks and stop the flow of fluids through the tubular members therein. Since there are diameter limitations, the length of the motors may be increased to develop the amount of motor horsepower required to drive the propellers. Use of light weight metals and plastics is maximized in motor manufacture to decrease average motor density. The electric motor may be of the three-phase, squirrel-cage induction type commonly used in driving downhole centrifugal pumps.

Conductor cable 77, which is provided with armor 83 to give adequate tensile strength passes into hollow shaft 85, which may be filled with an insulating low density liquid, through hermetic seal 87. Centralizing

means 89 is fixed to the shaft. Also attached to the shaft are electric motors 91 and 93 having rotors 95 and 97 mounted within stators 99 and 101, respectively. Electric power is supplied from cable 77 to the motors by conductors 103 and 105.

Rotation of marine screw propellers 73 and 75 provides forward thrust which is transmitted to shaft 85 by thrust bearings 107 and 109. This thrust in turn is transmitted to cable 77 to tug the conduit forward in the well bore until it reaches the desired position.

Three different motor-conduit combinations may be used with a conductive conduit. In the first a dense motor and instrumentation falls by gravity until the slope of the bore hole becomes too flat for rapid descent whereupon rotation of the propeller continues the downhole progress. A second combination is a neutrally buoyant conduit having descent in the more nearly vertical hole sections speeded by a weight, such as a mass of lead, which rests loosely upon ears on the lower end of the conduit. When descent of the weight slows, it may be pulled from the well and further advance of the conduit effected by propeller rotation. The third combination is completely neutrally buoyant with all descent being caused by propeller rotation.

In FIG. 10, another form of flexible conduit is shown, wherein the steam is circulated to the terminal end of the conduit 1 in a closed loop. In this form, the steam injection tubing extends to the vicinity of the terminal end of conduit 1 where it joins with condensate return conduit 27 as a closed loop. In the lower end 39 of the conduit the tubing 25 is not insulated so that the heat will be more effectively transferred to formation 43.

Alternatively, the amount of insulation around steam line 25 is gradually reduced to zero so that the rate of heat transfer from the condensing steam will be more uniform as indicated in FIG. 10. With this form of conduit the return condensate is lifted back to the surface by the pressure of the incoming steam.

With the form of conduit shown in FIGS. 1 through 4 it may be necessary to provide some form of artificial lift to facilitate the return of aqueous condensate to the surface. This artificial lift may be provided by injecting into the steam entering the upper end of the conduit a small percentage, such as 5% to 15%, by weight of an inert gas, such as nitrogen. This gas will enter the lower end of the condensate return line 27 and aid in lifting the conduit up through the flow line to the surface. As the pressure and temperature of the returning condensate decrease during the flow upward, there may be some flash vaporization of the returning condensate which would also aid in lifting the condensate to the surface. This returned inert gas is separated from the condensate in treater 31 before the condensate is returned to steam generator 15. If desired, the separated inert gas may be recompressed to or slightly above the steam injection pressure and reintroduced via flow line 119, compressor 121 and flow line 123 with the steam into flow line 21. Other artificial lift methods may be employed for aiding the return of the aqueous condensate including the use of gas lift valves in a manner similar to the use of gas lift valves 55 on the produced petroleum return line.

In the form of my invention shown in FIGS. 1-4, steam fills the major portion of the annular space inside that portion of the conduit lying within the petroleum bearing formation. Liquid condensate is collected near the terminal end of the conduit and is returned to the surface via tubular member 27. An alternate form of my invention is shown in FIGS. 11 and 12, wherein the

steam flow line 25 extends to the vicinity of the terminal end of the lower conduit sections, and the condensate return line 27 terminates at the end of the upper conduit section. By operating in this manner within the optimum steam flow rate range, the lower section of the conduit will be filled with a condensate-steam mixture which will have a higher coefficient of heat transfer to the conduit wall than dry steam or steam carrying a condensate mist. Where the lower, generally horizontal portion of the conduit is of substantial length of the order of several hundred feet or more, it may be desirable to provide several spaced perforations in steam flow line 25 so that the steam vapor is more uniformly distributed in the hot condensate. Alternatively, the insulation on the steam flow line may be gradually tapered down to zero from the thickness employed on that line in the upper section. Various other design modifications may be employed to achieve the desired result of a generally uniform rate of heat transfer from the circulating steam to the conduit walls.

Sealing means 131 surrounds the various tubular members carrying the steam, condensate returns and production to confine the hot steam-condensate mixture to the lower conduit section.

By the use of my invention it is possible to simultaneously heat the petroleum containing reservoir and produce the petroleum liberated therefrom through a single well bore.

Many modifications of my invention will be apparent to those skilled in the art and the specific embodiments shown hereinabove are intended as illustrative rather than limiting.

I claim:

1. A system for recovering petroleum from a petroleum containing formation penetrated by a well bore having a substantially horizontal portion within the petroleum containing formation and extending to the earth's surface comprising:

- a. a steam generator located at the earth's surface;
- b. a power source at the earth's surface;
- c. a flexible conduit extending from the earth's surface through a substantial length of the horizontal portion of the well bore, said conduit including:
 - (i) a pair of tubular members forming a closed loop for the circulating of steam from the steam generator to the vicinity of the lower terminal end of the conduit and return of aqueous condensate;
 - (ii) a separate tubular member extending to the vicinity of the lower terminal end of the conduit for conducting petroleum produced from the formation to the earth's surface; and
 - (iii) a means for conducting power from the power source to the lower terminal end of said conduit;
- d. means affixed to the end of the conduit for generating forward thrust upon the application of power thereto carried by said conduit; and
- e. at least one flow path interconnecting the exterior of the conduit within the petroleum containing formation and the separate tubular member.

2. The system of claim 1 wherein each of the tubular members forming the pair of tubular members has an upper end and a lower end, said lower end of each of said tubular members extending to the vicinity of said lower terminal end of the conduit and the closed loop is formed by joining together said lower ends of said tubular members.

3. The system of claim 1 wherein the lower end of a first of said pair of tubular members terminates in the

vicinity of said lower terminal end of said conduit, said first tubular member being spaced from said conduit to thereby form an annular space therebetween and wherein the lower end of a second of said pair of tubular members terminates at a point above the vicinity of said lower terminal end of said conduit; and wherein said closed loop is formed by said annular space between said lower ends of said tubular members.

4. The system of claim 3 wherein sealing means are provided surrounding the end of said second tubular member and the separate tubular member and power conducting means to prevent the flow of steam and condensate from the annular space within the lower end of the conduit into the annular space in the upper end of the conduit.

5. The system of claim 1 wherein the means for conducting power is an additional tubular member integral with said conduit for conducting liquid under pressure from the power source and the means for generating forward thrust is at least one rearwardly directed jet nozzle connected to said additional tubular member.

6. The system of claim 1 wherein the means for conducting power is an electric cable integral with the conduit for conducting electric power from the power source to the thrust generating means comprising at least one electric motor operation of which rotates a marine screw propeller in a direction to generate forward thrust.

7. The system of claim 1 including:

means for artificially lifting said aqueous condensate.

8. The system of claim 7 wherein said means for artificially lifting said aqueous condensate includes:

means for adding a gas to said steam at said earth's surface.

9. A system for recovering petroleum from a petroleum containing formation penetrated by a well bore having a substantially horizontal portion within the petroleum containing formation and extending to the earth's surface comprising:

- a. a steam generator located at the earth's surface;
- b. a power source at the earth's surface;
- c. a flexible conduit extending from the vicinity of end of the bore hole to the earth's surface, said conduit including:
 - (i) a pair of tubular members connected together in the vicinity of the terminal end of the conduit and forming a closed loop for circulation of steam from the steam generator through the conduit;
 - (ii) a separate tubular member extending to the vicinity of the lower terminal end of the conduit for conducting petroleum produced from the formation to the earth's surface; and
 - (iii) a means for conducting power from the power source to the lower terminal end of said conduit;
- d. means affixed to the lower terminal end of the conduit for generating forward thrust upon the application of power thereto; and
- e. perforations through the wall of at least a portion of the conduit within the petroleum containing formation for permitting the flow of petroleum through the perforations into the separate tubular member.

10. A method for producing a desired substance, having a viscosity which is decreased by an increase in temperature, from a subsurface stratum; said method comprising:

- a. forming a bore hole into said stratum;

- b. filling at least a portion of said bore hole with liquid;
 - c. inserting into said bore hole a flexible conduit neutrally buoyant in said liquid, said conduit comprising a fluid conveying means and means for increasing the temperature of said desired substance;
 - d. heating said desired substance by closed circulation of heated fluid through said flexible conduit; and
 - e. producing said desired substance.
11. The method of claim 10 including artificial lifting of said desired substance.

12. A method for recovering petroleum from a petroleum containing formation penetrated by a well bore having a substantially horizontal terminal portion of substantial length within the petroleum containing formation which comprises:

- a. introducing into the upper end of said well bore a flexible conduit including therein a pair of tubular members at least one of which extends to the vicinity of the terminal end of the conduit and which form a closed loop adapted for the circulation of hot fluid through the conduit, a separate tubular member extending from the vicinity of the terminal end of the conduit to the other end thereof for conducting produced petroleum, means for conducting power from one end of the conduit to the other, and means affixed to the terminal end of the conduit for generating forward thrust upon the application of power;
- b. introducing power into and through said power conducting means for activation of the thrust generating means to assist in the advance of the conduit through the well bore until said thrust generating means reaches the vicinity of the terminal end of the well bore;
- c. terminating the introduction of power to the upper end of said conduit and connecting one of said pair of tubular members to a steam generator;
- d. circulating steam through the closed loop formed by the pair of tubular members; and
- e. producing petroleum obtained from said formation through said separate tubular member.

13. The method of claim 12 in which the means for conducting power is the separate tubular member, the power is introduced in the form of liquid under elevated pressure, and the means for generating thrust is at least one rearwardly facing jet nozzle.

14. The method of claim 12 in which the means for conducting power are electrical conductors, the power introduced is electric, and the means for generating thrust is at least one marine screw propeller operated by an electric motor.

15. A method for recovering petroleum at the earth's surface from subterranean petroleum containing formations having insufficient reservoir pressure to cause the petroleum contained therein under reservoir conditions to drain into a well bore therein at an economically sufficient rate, said formation being penetrated by a well bore having a substantially horizontal terminal portion of substantial length within the petroleum containing formation which comprises:

- a. introducing into the upper end of said well bore a flexible conduit having at the terminal end thereof means for generating forward thrust upon the application thereto of power, said conduit having means integral therewith for transmitting power;
- b. during at least a portion of the continued introduction of the conduit introducing power via the

power transmitting means to operate the thrust generating means to move the conduit toward the terminal end of the well bore;

- c. terminating the introduction of power and circulating steam through the conduit at a pressure less than reservoir pressure to heat the petroleum and by lowering its viscosity causing it to flow into the well bore; and
- d. producing petroleum entering said well bore via a flow tubing carried by said conduit for recovery at the earth's surface.

16. The method of claim 15 in which artificial lift means are employed to assist in lifting the produced petroleum to the earth's surface.

17. The method of claim 15 in which at least the upper end of the flexible conduit is provided with gas lift valves communicating with the flow tubing and a gas under pressure is introduced into the upper end of the well bore to assist in lifting the produced petroleum to the earth's surface.

18. A system for recovering petroleum from a petroleum containing formation penetrated by a well bore having a substantially horizontal portion within the petroleum containing formation and extending to the earth's surface, said system comprising:

- a. a steam generator located at the earth's surface;
- b. a power source at the earth's surface;
- c. a flexible conduit extending from the earth's surface through a substantial length of the horizontal portion of the well bore comprising a lower section lying within the petroleum containing formation and an upper section extending from the end of the lower section to the earth's surface, said conduit including:

(i) a pair of tubular members, one of which extends to the vicinity of the terminal end of the conduit and the other of which terminates at the end of the upper section of the conduit;

(ii) sealing means surrounding said pair of tubular members at the end of the upper section of the conduit so that the tubular members form a closed loop for the circulation of steam from the steam generator to the vicinity of the terminal end of the conduit and return of aqueous condensate, with the free space within the conduit in the lower section thereof being a portion of such closed loop;

(iii) a separate tubular member extending to the vicinity of the terminal end of the conduit and passing through the sealing means for conducting petroleum produced from the formation to the earth's surface; and

(iv) means for conducting power from the power source to the terminal end of said conduit;

- d. means affixed to the terminal end of the conduit for generating forward thrust upon the application of power thereto carried by said conduit; and
- e. at least one flow path interconnecting the exterior of the lower section of the conduit and the separate tubular member.

19. A method for recovering petroleum from a subterranean petroleum containing formation penetrated by a well bore having a substantially horizontal terminal portion of substantial length within the petroleum containing formation which comprises:

- a. introducing into the upper end of said well bore a flexible conduit having at the terminal end thereof means for generating forward thrust upon the ap-

- plication thereto of power, said conduit having means integral therewith for transmitting power;
- b. during at least a portion of the continued introduction of the conduit introducing power via the power transmitting means to operate the thrust generating means to move the conduit toward the terminal end of the well bore;
- c. terminating the introduction of power and circulating through the conduit a mixture of steam and an inert gas to heat the petroleum contained in the petroleum containing portion of the reservoir to lower its viscosity and cause the petroleum to flow into the well bore; and
- d. producing the petroleum entering the well bore via a flow tubing carried by said conduit for recovery at the earth's surface.
20. The method of claim 19 in which the inert gas content of the mixture of steam and inert gas lies within the range of from 5% to 15% by weight.
21. A method for recovering petroleum from a petroleum containing formation penetrated by a well bore having a substantially horizontal terminal portion of substantial length within the petroleum containing formation which comprises:
- a. introducing into the upper end of said well bore a flexible conduit including therein a pair of tubular members at least one of which extends to the vicinity of the terminal end of the conduit and which form a closed loop adapted for the circulation of hot steam through the conduit and a separate tubular member extending from the vicinity of the terminal end of the conduit to the upper end thereof for conducting produced petroleum;
- b. circulating steam through the closed loop formed by the pair of tubular members; and
- c. concurrently producing petroleum obtained from said formation through said separate tubular member.
22. A system for recovering petroleum from a petroleum containing formation penetrated by a well bore having a substantially horizontal portion within the petroleum containing formation and extending to the earth's surface comprising:
- a. a steam generator located at the earth's surface;
- b. a flexible conduit extending from the earth's surface through a substantial length of the horizontal portion of the well bore, said conduit including:
- (i) a pair of tubular members forming a closed loop for the circulation of steam from the steam generator to the vicinity of the terminal end of the conduit and return of aqueous condensate;
- (ii) means for controlling the rate of heat flow to selected portions of the petroleum containing reservoir by varying the coefficient of heat transfer from the conduit; and
- (iii) a separate tubular member extending to the vicinity of the terminal end of the conduit for conducting petroleum produced from the formation to the earth's surface; and
- c. at least one flow path interconnecting the exterior of the conduit within the petroleum containing formation and the separate tubular member.
23. A system for recovering petroleum from a petroleum containing formation penetrated by a well bore and extending to the earth's surface, said system comprising:
- a. a steam generator located at the earth's surface;
- b. a power source at the earth's surface;

- c. a conduit extending from the earth's surface through said well bore, said conduit including:
- (i) a pair of tubular members forming a closed loop for the circulating of steam from the steam generator to the vicinity of the lower terminal end of the conduit and return of aqueous condensate;
- (ii) a separate tubular member extending to the vicinity of said lower terminal end of the conduit for conducting petroleum produced from the formation to the earth's surface; and
- (iii) a means for conducting power from the power source to said lower terminal end of the conduit;
- d. means affixed to the terminal end of the conduit for generating forward thrust upon the application of power thereto carried by said conduit; and
- e. at least one flow path interconnecting the exterior of the conduit within the petroleum containing formation and the separate tubular member.
24. The system of claim 23 including: means for artificially lifting said aqueous condensate.
25. The system of claim 24 wherein said means for artificially lifting said aqueous condensate includes: means for adding a gas to said steam at said earth's surface.
26. A system for recovering petroleum from a petroleum containing formation having a well bore extending from the earth's surface into said formation, said system comprising:
- a. a steam generator located at the earth's surface;
- b. a conduit extending from the earth's surface and into said formation;
- c. means for providing a closed loop flow path for circulating steam from said steam generator to the vicinity of said terminal end of said conduit and to return aqueous condensate to the earth's surface; and
- d. means for providing a separate flowpath for conducting petroleum produced from the formation to the earth's surface; and
- e. means for artificially lifting said aqueous condensate.
27. The system of claim 26 wherein said means for artificially lifting said aqueous condensate includes: means for adding a gas to said steam at said earth's surface.
28. The system of claim 27 wherein said means for providing a closed loop flowpath comprises:
- a. first tubular member within said conduit and extending from the earth's surface and having the lower end thereof terminating in the vicinity of said lower terminal end of said conduit, said first tubular member being spaced from said conduit to thereby provide an annular space therebetween; and
- b. a second tubular member within said conduit and extending from the earth's surface and having the lower end thereof terminating at a point above the vicinity of said lower terminal end of said conduit with said lower end of fluid communication with said annular space; and
- sealing means surrounding said lower end of said second tubular member and said separate tubular member to prevent the flow of steam and condensate from said annular space unto said conduit above said sealing means.
29. The system of claim 27, wherein said means for providing a closed loop flowpath comprises:

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a first tubular member within said conduit and extending from the earth's surface and having a lower end terminating in the vicinity of said lower terminal end of said conduit;
a second tubular member within said conduit and extending from the earth's surface and having a

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lower end terminating in the vicinity of said lower terminal end of said conduit; and
conduit means for joining said lower ends of said first and second tubular members together.

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United States Patent [19]

Mims et al.

[11] Patent Number: **4,532,986**[45] Date of Patent: **Aug. 6, 1985**[54] **BITUMEN PRODUCTION AND SUBSTRATE STIMULATION WITH FLOW DIVERTER MEANS**

[75] Inventors: Donald S. Mims; Richard H. Widmyer, both of Houston, Tex.

[73] Assignee: **Texaco Inc.**, White Plains, N.Y.[21] Appl. No.: **491,832**[22] Filed: **May 5, 1983**[51] Int. Cl.³ **E03B 3/11**[52] U.S. Cl. **166/30; 166/52; 166/191**[58] Field of Search **166/272, 303, 50, 52, 166/191, 127, 77, 72; 299/2, 15/104.15, 104.16-104.19, 104.2**[56] **References Cited****U.S. PATENT DOCUMENTS**

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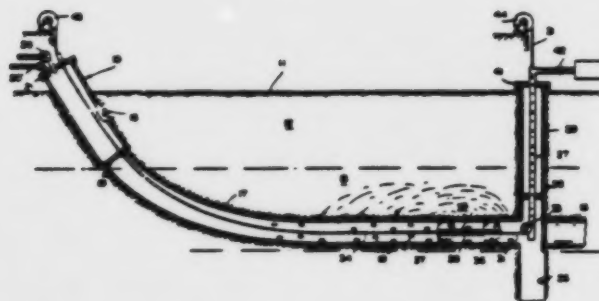
Primary Examiner—Stephen J. Novosad

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[57] **ABSTRACT**

A well completion, and method for recovering heavy hydrocarbons or bitumen from a subterranean formation. The completion includes a well liner which lies in a generally horizontal disposition within a hydrocarbon holding substrate to define the main or primary well. A secondary well which extends to the surface intersects the main well to communicate therewith. Said secondary well includes means to conduct a stream of hot stimulating fluid into the main well. A fluid impervious barrier or flow diverter means positioned within the main well between the injection end and the production end, establishes a pressure differential across the barrier. The barrier urges stimulating agent into the substrate at a desired location, thereby creating a heated path along which the bitumen emulsion flows toward the well's production end. Means is provided in the secondary well to position the impervious barrier from one end of the main well to the other.

6 Claims, 2 Drawing Figures

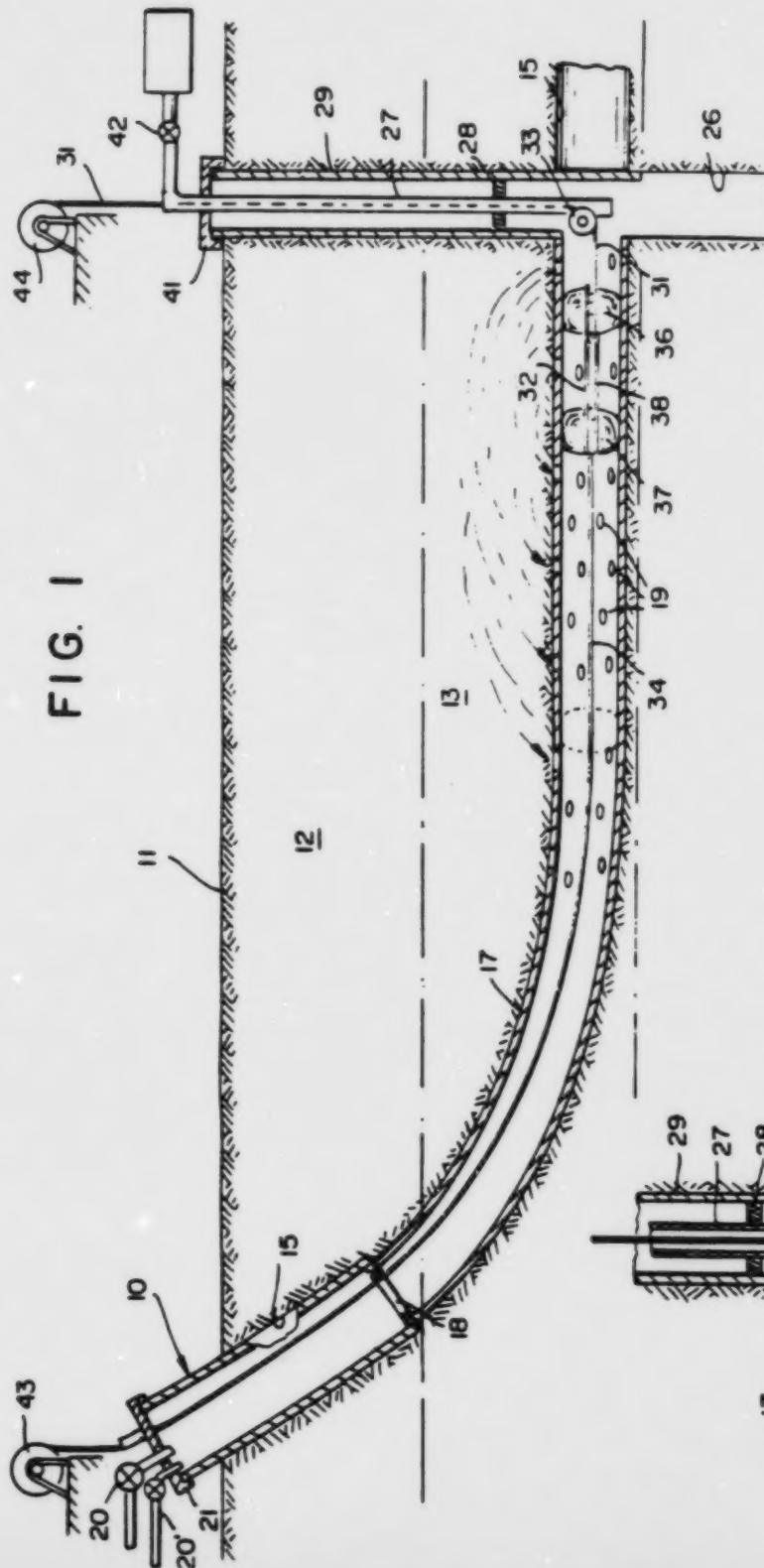


FIG. 1

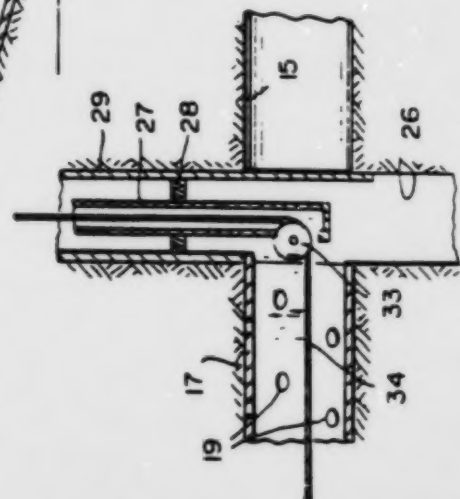


FIG. 2

BITUMEN PRODUCTION AND SUBSTRATE STIMULATION WITH FLOW DIVERTER MEANS

BACKGROUND OF THE INVENTION

In the production of viscous hydrocarbon such as heavy crude and bitumen from tar sands, it is necessary to thoroughly stimulate the viscous material by lessening its viscosity to flowable condition. Thus, the bitumen, in emulsion form, can flow or be withdrawn from the substrate.

Usually thermal stimulation comprises the introduction of a pressurized flow of a heating medium such as steam into the substrate by way of an injection well. In the instance of tar sands, this step, over a period of time, liquefies the bitumen and releases it from its retained condition in the tar sand. It also establishes a pressure front whereby to urge the now flowable hydrocarbons toward one or more spaced apart production wells.

Although the hereinafter described method and apparatus can be applied to the production of either bitumen or heavy crude oil, the following disclosure will define the invention in terms of the production of bitumen from tar sands.

A preferred, and presently used method adapted to viscous hydrocarbon production utilizes a single well which is sequentially heated, and produced to operate on a cyclical principle. More specifically, the substrate surrounding the well is initially preheated under pressure to convert bitumen into flowable condition.

Thereafter, during a soak period, steam is condensed, and heat is absorbed into the substrate thereby causing bitumen emulsion to gravitate toward the lower pressure well and be produced therefrom.

When, over a period of time, the pressure within the substrate becomes depressed, it is necessary to recommence the cycle by the further introduction of a stimulating medium. As a sufficiently high heat and pressure environment is reestablished and bitumen emulsion is again caused to flow, steam injection is discontinued or minimized. Further controlled draining of bitumen emulsion can now be resumed.

This cyclical process can be repeated indefinitely until the area adjacent to the well becomes exhausted of hydrocarbon product. The method is generally referred to as the huff and puff process. It is found to function effectively particularly when the stimulating medium is steam.

In an alternate prior art method of producing hydrocarbons from a substrate, a plurality of vertical wells are drilled in a desired pattern. Thereafter, the stimulating fluid such as steam, under pressure, is injected for a period of time into the substrate by way of a centrally located injector well.

The heated or stimulated area about the well will gradually be widened, thereby establishing an expanding pressure front. The latter urges flowable bitumen emulsion toward the surrounding producing wells. This process is advantageous in that it can be practiced by a continuous, rather than a cyclical introduction of stimulating fluid.

Tar sand deposits generally occur in horizontal layers. It has been found desirable therefore, toward achieving an improved production rate to utilize a generally horizontally disposed well for producing from the layer. However, the nature of the horizontal well mandates that the latter operate on a cyclical basis to realize an appreciable outflow of bitumen emulsion.

Since this cyclical operation amounts to disruption of the producing phase, it constitutes a less than desirable expedient.

To increase the rate of production from a horizontal well of the type contemplated, there is presently provided an efficient method and apparatus for establishing a flowable bitumen emulsion in and through a tar sand environment. The process is effectuated through use of an elongated, horizontal well which traverses at least a portion of the tar sands layer.

A vertical well is positioned to intersect the horizontal well, and serves to facilitate the producing process as well as to provide communication with the horizontal well.

Operationally, both the horizontal well and the adjacent substrate are initially preheated to establish a favorable operating temperature at which fluidized bitumen emulsion can flow. The horizontal well liner embodies a liner which includes a reciprocally, longitudinally adjustable barrier means therein to divert the stimulating steam outwardly and thereby create a pattern of hot paths along which subsequent bitumen emulsion flows. Said hot paths communicate the relatively high pressured injection area where the stimulating fluid is introduced, with a lower pressure area of the liner through which production takes place.

Thereafter, and subsequent to the preheating step, the well is produced by the controlled introduction of hot stimulating fluid as needed. This latter introduction, together with regulation of the well back pressure, causes fluidized bitumen emulsion to be urged to the well producing end.

As one area of the adjacent substrate becomes depleted of bitumen, the steam flow path pattern is altered by adjusting the location of the steam diverting barrier along the well liner. Thus, the area about the horizontal well is swept thoroughly and efficiently of contained bitumen.

It is therefore an object of the notion to provide the method and apparatus for improving production output of a viscous hydrocarbon fluid from a subterranean reservoir in which the fluid is locked. A further object is to provide a method and apparatus for thermally stimulating and producing a well aligned substantially horizontally within a formation which contains a relatively viscous hydrocarbon, which well includes means for diverting the flow of a stimulating medium to improve the well's efficiency. A still further object is to provide a method and apparatus for the continuous production of viscous hydrocarbon fluids from a main well disposed substantially horizontally through a bitumen holding formation, which main well cooperates with a secondary well and includes means for selectively diverting a stimulating medium flow into the substrate.

DESCRIPTION OF THE DRAWINGS

In the drawings,

FIG. 1 is an elevation view in cross-section showing a well completion of the type contemplated.

FIG. 2 is an enlarged segmentary view of a part of FIG. 1.

Referring to the drawings, a well 10 of the type contemplated is shown, which can enter the ground at a vertical or near vertical alignment. Preferably the well is disposed at an angle to the ground surface 11. The well bore 14 is initially commenced through overbur-

den 12 which overlies the productive or tar sand layer 13.

Thereafter, partway through the overburden layer the well bore is deviated from its original direction in a manner that at least a segment of it lies in a generally horizontal relationship with respect to the earth surface 11. Preferably the well bore extends coextensively with the tar sand layer. Further, it is preferably positioned at such a depth as to be adjacent to the lower border of the hydrocarbon containing layer 13.

Following usual drilling and completion practice, well bore 14 is provided at the upper end with a series of casing lengths 16. The latter can progressively decrease in size and are grouted in a manner best suited to the condition.

An elongated liner 17 is inserted through the respective casing 16, being supported at the lower end of casing 16 by a liner hanger 18. The latter is structured to allow passage of hot bitumen emulsion therethrough during the producing stage.

Structurally, one embodiment of elongated liner 17 comprises a steel tubular member which is perforated along that portion thereof which lies within tar sand layer 13. The perforation 19 in the liner wall can embody ordinary holes, or alternately slotted openings which extend either horizontally, or circumferentially through the liner wall.

In any event, liner openings 19 are sufficiently large in diameter to permit a pressurized discharge of heating medium therethrough and into the tar sand substrate 13. Further, these openings 19 allow the return flow of hot bitumen emulsion thereto when the latter is in flowable condition.

The upper or external end of liner 17 is provided with a closure such as a well head 21. The latter includes a series of valves 22 and 23 which are operable to regulate the flow of the heating medium flowing into the well, as well as to maintain a desired pressure within liner 17.

Horizontal well 10 can extend for a desired distance through the tar sand layer 13 to a length at which it might effectively operate.

At the remote or buried end of horizontal well 10, a second well 26 is formed. Said second well is located such that it intersects first well 10 in the region of the far end thereof. Second well 26 is presently shown and described as being in a substantially vertical alignment relative to surface 11. It can however be inserted into substrate 12 at an angle to intercept the first well 10's region at a predetermined desired angle.

Second well 26 includes a liner or casing 29 which extends therethrough to terminate approximately at the intersection region of the two well bores. A fluid conductor or conduit 27 is positioned within second well 26. The latter comprises primarily an elongated tube-like member having a packer 28 at the lower end thereof. Packer 28 is operable to expand and engage the adjacent wall of casing 29 whereby to form a fluid tight seal with the latter and to avoid back flow of heating fluid which is discharged from conduit 27.

Well 10 is provided with barrier means assembly 31, such as a bridge plug. Said barrier means 31, functions to block, and divert a flow of heating fluid which enters horizontal liner 17, outwardly and into the substrate 13.

Barrier, or flow diverter means 31 as shown, comprises in one embodiment an axially elongatable or expandable member 32 having two or more outwardly expandable barrier elements 36 and 37, such as two or more bridge plugs at opposed ends thereof. Said barrier

elements 36 and 37 are of the type often associated with well treatment procedures. Functionally, they can, when actuated, expand outwardly to engage adjacent liner walls. Each diverter then forms a transverse barrier in the liner 17 to segregate a section of the well whereby to avoid entry of stimulating fluid thereto. The barrier 31 is connected to or removably engaged with barrier 34 setting conduit, which, although not presently shown, extends from a controllable source of a fluid at the surface, to the respective expandable members 36 and 37. The latter can embody a conductor. Said conduit is capable of carrying an activating fluid to the latter thereby to controllably adjust said members between expanded and contracted positions.

Operationally, by longitudinally adjusting the position of barrier assembly 31, the latter can be urged through the liner 17 in any direction, as needed. At the commencement of a producing operation, preferably barrier 31 is initially positioned at the remote end of liner 17.

Hot stimulating fluid can thus be introduced by way of conduit 27 to horizontal liner 17, and thence diverted into the surrounding substrate 13. This initial application of heat is achieved either by injection through well head 21 at the horizontal well, or preferably through conduit 27 in well 26.

The latter as shown includes a cap 41 through which conduit 27 passes, and which embodies a flow control valve 42. When conduit 27 is communicated to a source of pressurized steam or stimulating fluid at 43, flow of the latter toward well 10 can be readily regulated either for preheating the substrate or for producing.

In a preferred operation, hot stimulating fluid such as pressurized steam will flow initially from conductor 27, into horizontal well 10 at the injection segment of the well as defined by the fixedly positioned barrier 31. The steam will thus be diverted under pressure, into the surrounding substrate 13. Over a period of time it will form a heated progressively expanding stimulated volume.

During this initial heating period, steam will condense to hot water, which in turn will contact the liquefied hydrocarbon or bitumen to form a flowable emulsion, or more accurately, a flowable mixture.

Since the stimulant is injected under a pressure, usually of about 300 psi, the hot stimulating fluid will tend to form pathways through the substrate merely by liquefying the bitumen to flowable state. The presence of fluid barrier or diverter 31 within horizontal well 10 in effect divides the latter into two discrete segments. One of the segments at the injection end will ordinarily be subject to a higher pressure than the downstream or producing segment. Thus, as liquefied bitumen forms into an emulsion or mixture, it will move toward the lower pressure end of well 10 and thereby enter liner 17 through ports 19.

By maintaining the position of barrier 31, and with the continued injection of steam, a steady flow of bitumen emulsion will pass into the production end of liner 17.

The production rate of bitumen emulsion can be facilitated and controlled by adjusting the pressure at well head 21. More specifically the rate of production can be altered by adjusting the back pressure through valves 22 and 23 at well head 21. Thus the flow of the hot bitumen emulsion can be encouraged by reducing the pressure in liner 17 even to the point of establishing a vacuum therein.

Over a period of time, the establishment of the bitumen flow path through the tar sand substrate 13 will exhaust that particular area of available bitumen. It is desirable, and even necessary therefore to adjust the flow paths which communicate the liner producing and injection ends. This is achieved by causing or forcing hot stimulating fluid to enter an area not heretofore fully contacted.

Physically this is done by adjusting the position of the barrier 31 within the longitudinal well 10. More particularly it is effectuated by displacing barrier 31 from its original position, toward the well producing end. Alternatively it is possible to insert another barrier into liner 17 at a position closer to well head 21 thereby in effect extending the barrier length.

Thereafter, further injection of steam into conductor 27 and well 10 will cause movement of the stimulating fluid into heretofore unaffected areas of substrate 13. Overall, the stimulated area of layer 13 will be progressed toward well head 21, thereby further releasing additional bitumen and establishing a new flow path for emulsion to enter liner 17.

After a period of operation, the rate of production at well head 21 will indicate that the section of layer 13 being drained, has been substantially depleted. Barrier 31 can then again be repositioned in either direction along line 17 and a further set of flow paths established or extended into new areas.

To facilitate the controlled reciprocal movement of barrier assembly 31, the latter as noted is provided in one embodiment, with a surface operated cable system. Said system, together with suitable packer actuating conduits, permits the respective packers or barrier elements 36 and 37 to be adjusted to the contracted position and pulled to a desired location. Thereafter reactivation of the packers to an expanded condition fixes the barrier assembly within liner 17.

The shown cable system which is capable of sliding barrier assembly 31 in either direction through liner 17 can comprise a number of cables to achieve the desired function.

For example, to operate most efficiently, each packer 36 and 37 is so connected to the cable system such that each thereof can be positioned independently of the other. However, in that both packers 36 and 37 are under particular circumstances adjusted simultaneously, they can be mutually connected in such manner as to be moved concurrently by the cable system.

In one operable cable system, cable 38 which is attached to one end of barrier assembly 31 is guided through liner 17 and thence through conductor 27 by means of a spool 39. The latter as shown in FIG. 2 can be rotatably mounted directly to conduit 27 in a manner to allow unhampered movement of the spool and yet permit the free passage of stimulating fluid. The latter as noted is conducted from the source 43, through control valve 42, and downwardly through said conductor and into liner 17.

At the surface, cable 38 is passed through a packing gland or similar fluid tight member within conduit 27 such that the cable can be mounted to a cable take-up mechanism 44. The cable other end 35 is connected to the well head end of barrier means 31, and thence to a second cable take-up mechanism 46.

It is clear from the disclosed arrangement that it is possible, through the selective manipulation of the cables 34 and 38, to regulate the position of barrier 31 anywhere along the length of liner 17.

Thereafter, by the timed movement of barrier means 31, together with introduction of hot stimulating fluid, the rate of bitumen production can be maximized. Further, a higher degree of efficiency can be realized since a more expanded area of the substrate will be swept by the stimulating fluid.

Operationally, barrier 31 can be moved at will in either direction through liner 17. Further, it can be expanded or retracted axially within limitation, thereby to vary the barrier length. Thus, entire lengths of liner 17 can be readily exposed to the most effective injection program.

Although modifications and variations of the invention can be made without departing from the spirit and scope thereof, only such limitations should be imposed as are indicated in the appended claims.

We claim:

1. Well completion for a substrate layer holding viscous hydrocarbons which are produced in response to thermal stimulation of the substrate through the injection of a hot stimulating fluid therein, which completion includes;

a elongated well liner at least a portion of which is disposed in a first well bore formed within the substrate, said at least portion of said elongated well liner being perforated and extending in a substantially horizontal alignment through said substrate layer to receive a flow of hydrocarbon emulsion, and having a well head forming a liner production end,

at least one secondary well in the substrate and terminating with its lower end in a region adjacent to a portion of the first well bore,

a substrate stimulating system including; a conduit means in said at least one secondary well which is adapted at one end to communicate with a source of a hot pressurized stimulating fluid, said conduit means other end opening adjacent to the first well bore whereby to introduce a pressurized flow of the hot stimulating fluid into the liner remote end, flow diverter means movably positioned within said well liner and being actuatable between expanded and contracted modes to form a transverse barrier in the liner and to interrupt fluid flow there-through,

flow diverter positioning means engaging said diverter means and being operable to controllably adjust the diverter means' location along the liner length thereby to alter the flow of stimulating fluid into the substrate, said flow diverter positioning means includes;

a discontinuous cable means extending through the respective first well bore and secondary well, and being connected to opposed ends of the diverter means whereby to reciprocally adjust the location of the diverter means within said liner and means to separately apply tension to the cable means in one of said wells while concurrently reducing tension to the cable means in the other well said discontinuous cable means being registered within said conduit means in said secondary well.

2. In the apparatus as defined in claim 1, wherein said diverter means includes;

at least two spaced apart members, each being individually expandable within the well liner to form spaced apart fluid tight seals with said elongated liner wall.

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3. In the apparatus as defined in claim 2, wherein each of said at least two spaced apart members is connected to the cable means and operably connected to each other to be concurrently or independently adjusted within the elongated liner.

4. In the apparatus as defined in claim 2, wherein each of said at least two spaced apart members is separately connected to one segment of the discontinuous cable means, and adapted to be selectively located within the liner independently of the other of said spaced apart members.

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5. In the apparatus as defined in claim 1 wherein said flow diverter positioning means includes: said fluid conduit means (27) in said secondary well being communicated with a pressurized source (43) of steam and a spool (39) at the conduit (27) lower end adjacent to said first wellbore, and said discontinuous cable means within said conduit being registered in said spool (39).

6. In the apparatus as defined in claim 5 including: sealing means (28) carried at the lower end of said fluid conduit means (27) being expandable to form an annular seal with said casing (29) in said secondary well.

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United States Patent [19]

Richards

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 [45] **Date of Patent:** **Aug. 6, 1985**

 [54] **PROCESS FOR PRODUCTION OF OIL AND GAS THROUGH HORIZONTAL DRAINHOLES FROM UNDERGROUND WORKINGS**

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 [52] **U.S. Cl.:** **299/2; 166/369; 299/11; 299/18**

 [58] **Field of Search:** **166/30, 369; 175/62; 299/2, 7, 11, 12, 18, 19**

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Attorney, Agent, or Firm—Fowler, Lambert & Hackler

 [57] **ABSTRACT**

A method for collecting oil from a plurality of spaced apart oil-bearing subterranean formations includes the steps of drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced apart oil-bearing formations, excavating a working area at selected oil-bearing subterranean formations and thereafter drilling a plurality of generally horizontal boreholes from each of the working areas into the selected oil-bearing subterranean formations. Thereafter, oil collection troughs are excavated within each of the working areas to collect oil from the boreholes and conduct the collected oil into a sump from which the oil is raised to the earth's surface utilizing a single lift. During collection and raising of the oil from each of the spaced apart oil-bearing subterranean formations, the shaft and working areas are sealed.

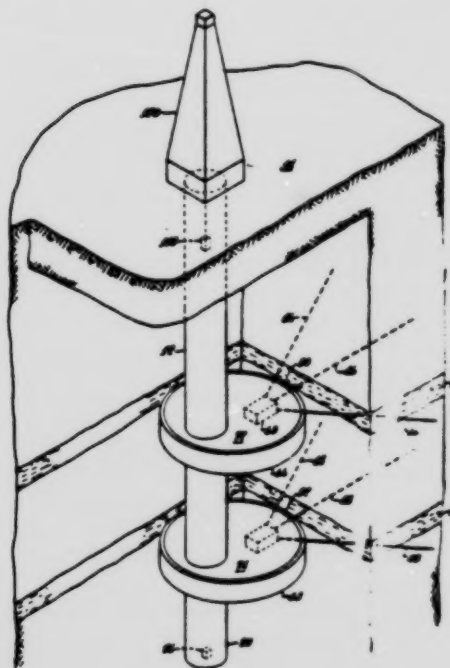
21 Claims, 2 Drawings


FIG. 1.

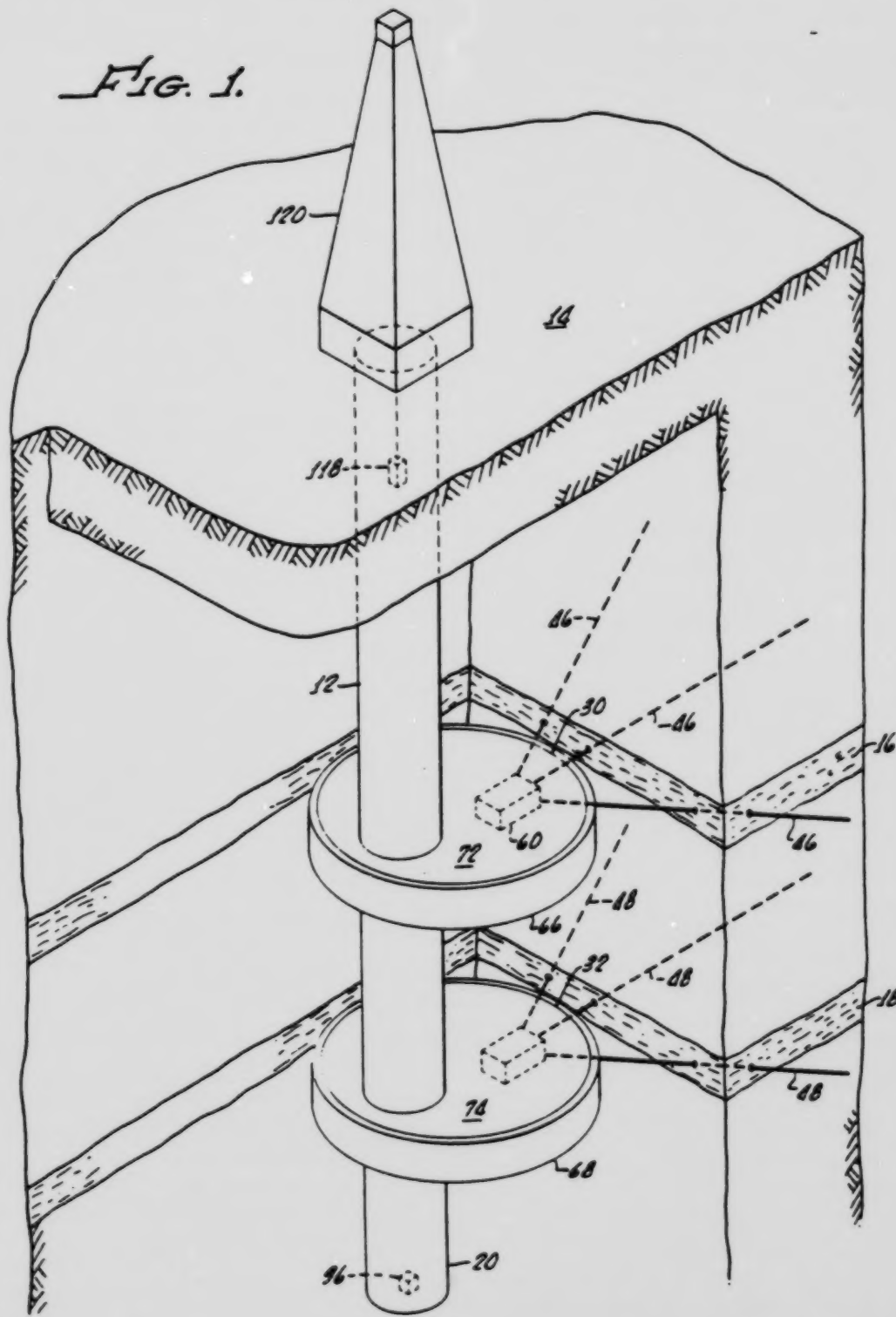
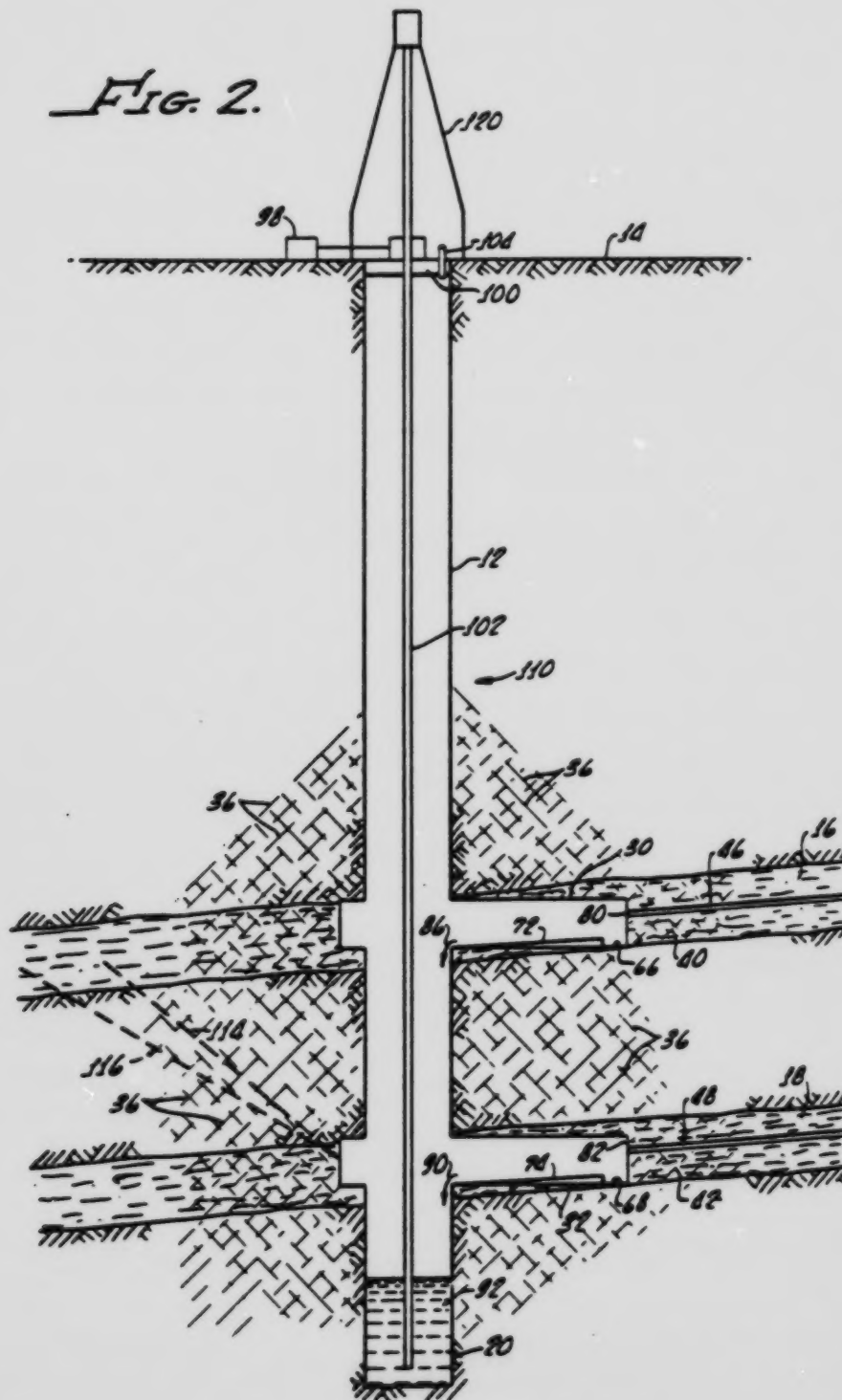


FIG. 2.



PROCESS FOR PRODUCTION OF OIL AND GAS THROUGH HORIZONTAL DRAINHOLES FROM UNDERGROUND WORKINGS

BACKGROUND OF THE INVENTION

This invention relates generally to methods and apparatus for the recovery of oil and gas from underground formations, and more particularly to the recovery of oil from known oil depleted formations and geological formations having properties and characteristics not considered heretofore to be suitable for economic recovery of the oil.

Recovery of oil from underground formations necessarily requires some flow of the oil through the formation to reach a point where it is typically lifted by mechanical means to the earth's surface. It should be readily apparent that the flow rate of the oil, since it is viscous liquid, through the rock formation depends on many factors, which include the hydraulic head of the oil, the thickness and permeability of the formation as well as the density and viscosity of the oil therein.

Many methods have been developed to increase the recovery of oil from underground formations. Typically, these methods have been of the secondary recovery type and utilized only after the collection or production rate of oil falls below an economically acceptable level. Many of the methods have been based on increasing the proximity or exposure of the drainhole path to the petroleum within the oil-bearing formation.

For example, as far back as 1920, Ehrat, in U.S. Pat. No. 1,660,187, described a method of recovering oil and gas from one or more oil-bearing strata in which galleries were excavated underneath the strata and boreholes were drilled upwardly from the galleries into the oil-bearing strata. The galleries were connected to a shaft leading to the earth's surface and all of the boreholes lined with tubes for collecting the oil and gas and for conducting it to the earth's surface by a system of pumps and piping.

This method, however, did not utilize horizontal holes drilled within the oil-bearing strata for the recovery of oil. Horizontal holes are far more effective in the recovery of oil from oil-bearing strata because of the proximity of the drainhole path to the petroleum to be collected.

It is also apparent that a horizontal borehole within an oil-bearing formation is more efficient for collecting oil therefrom than vertical holes or taps, because, in general, more borehole exposure within the oil-bearing formation is possible with the horizontal holes.

Another factor in the economic feasibility in oil recovery methods is the amount and cost of maintaining the collection system established by the method.

For example, maintenance of the Ehrat system is expensive because of the number of tubes, valves and pipes necessary to conduct the oil and gas to the earth's surface. Since the Ehrat galleries are ventilated and personnel must be present to attend the system, additional expense is incurred such as continual safety inspections, mandated by the Bureau of Mines, during the operation of the recovery method.

Ranney recognized the advantages of horizontal drilling for oil within formations, in the June issue of *The Petroleum Engineer*, in 1939, in an article entitled, "The First Horizontal Oil Well," and in his U.S. Pat. Nos.

2,280,851 issued on Apr. 28, 1942, and 2,365,591 issued on Dec. 19, 1944.

Ranney noted that horizontal wells are far more effective than vertically drilled wells in sands such as the Alberta tar sands. With regard to recovering oil from the Alberta tar sands, Ranney noted that, "something more than the mere drilling of a horizontal well must be resorted to." Ranney thereafter teaches methods for delivering a reagent into oil-bearing formations under conditions to recover the oil disposed about horizontal drill holes.

Not envisioned by Ranney, was the use of horizontal holes in multiple oil-bearing strata to recover or collect oil or the economics of utilizing a plurality of spaced-apart oil-bearing formations in a sealed system to recover oil.

As is apparent in FIG. 2, and within the specification of U.S. Pat. No. 2,365,591, Ranney contemplated a complex valve and piping arrangement for the injection fluids and for the recovery of dissolved oil therefrom. All of this necessitated access to the underground equipment during production and, as hereinabove pointed out, in connection with Ehrat, such an accessible oil recovery system causes a less favorable economic operation of the oil collection system.

Horizontal boreholes were also used in the methods of Turk, described in U.S. Pat. No. 4,160,481 issued on July 10, 1979, and Allen in U.S. Pat. No. 4,257,460 issued on Mar. 21, 1981. Although these methods employed generally horizontal holes drilled into underground oil-bearing formations, they primarily were directed to creating oil-driving forces by the injection of steam and/or inert gas in order to force the oil from the stratum into the horizontal boreholes.

As pointed out in Turk, a number of generally horizontal boreholes may be drilled from a shaft in a radial-like manner into an oil-bearing formation, and these radial horizontal holes may be positioned at a slight upward angle relative to their respective shaft hole in order to accommodate gravity flow of the oil in the formation. The drilling of holes in this manner also facilitated the use of a leaching fluid, which is injected through a portion of each horizontal hole in order to leach the oil therefrom back into the shaft.

It certainly can be appreciated that this leaching operation, whether it be with a solvent, with steam or an inert gas, as described in Allen, requires a significant amount of underground piping and valves, in addition to costly ventilation of the working areas to enable workmen to enter into the shafts and working areas for the purpose of operating the system to recover oil.

Although work has been progressing since 1920 regarding methods of collecting oil and gas from underground formations and particularly from underground formations from which the easily recovered oil has been collected, there has yet to be developed an economical method, or process, for removing oil from known formations having a plurality of spaced-apart oil-bearing strata.

The present invention is directed to a process utilizing horizontal holes drilled in a plurality of spaced-apart subterranean oil-bearing formations.

All of the previous work with the drilling of horizontal holes in underground formations was done at a single level, without any of the researchers realizing the economy in drilling horizontal holes into a plurality of spaced-apart oil-bearing strata.

Further, it has not been recognized that the utilization of a plurality of horizontal holes drilled from a single vertical shaft into a plurality of underground oil-bearing formations can be used as a collection system itself without the need for an extensive and expensive underground piping and valves, which must be maintained and operated by personnel, the latter requiring ventilation throughout the shaft and working areas, which is expensive, adds to the expense, and requires constant safety inspections.

The present invention overcomes all of the problems confronting the prior investigators and provides for a method or process for collecting oil and gas from a plurality of spaced-apart underground oil-bearing formations by the utilization of horizontal holes in a sealed collection system.

SUMMARY OF THE INVENTION

A method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, in accordance with the present invention, includes the steps of drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations, excavating a working area at selected oil-bearing subterranean formations with each of the working areas communicating with the shaft, drilling a plurality of generally horizontal boreholes from each of the working areas into the selected oil-bearing subterranean formations, collecting oil from the boreholes and conducting the oil through the working areas and thereafter through the shaft to the earth's surface.

To facilitate the drilling, or sinking, of a shaft from the earth's surface and the excavation of a working area at selected oil-bearing subterranean formations, without the flooding of the shaft and working area with oil and/or water, grout may be injected at selected oil-bearing subterranean formations to form a grout curtain. Thereafter, the working area at the selected oil-bearing subterranean formations, are formed within the grout curtain and the drilling of generally horizontal boreholes from the working areas are drilled through the grout curtain into the oil-bearing formations.

Also, in accordance with the method of the present invention, an open oil collection trough means may be excavated within each working area for the collection of oil flowing from all of the generally horizontal boreholes and for conveying the collected oil into the shaft, where it drops into a sump area thereof excavated below a lowest oil-bearing formation from which oil is to be collected.

The shaft and the working areas may be thereafter sealed and oil allowed to flow from the horizontal holes into the trough means and thereafter into the sump from which it is lifted to the earth's surface.

Gas may also be collected within the shaft and removed therefrom as the oil is collected.

It should be appreciated that there is no complex piping or valving arrangement necessary in the method of the present invention for collecting oil or gas. Neither is there any necessity for access to any of the working areas after the boreholes have been drilled and put into operation. Hence, there are no ventilation requirements, and no continual safety inspection necessary, in conjunction with having men and/or manually-operated equipment in the shaft and working areas during oil production.

BRIEF DESCRIPTION OF THE DRAWINGS

The advantages and features of the present invention will appear from the following description considered in conjunction with the accompanying drawings, in which:

FIG. 1 is a perspective representation of a system excavated, in accordance with the method of the present invention, showing generally in cross-section a plurality of oil-bearing formations, a shaft, a working area at each of the oil-bearing formations, with each working area having an open collection trough, or ring, for the collection of oil; and,

FIG. 2 is a cross-sectional representation of a shaft and working area excavated in accordance with the present invention, generally showing working areas excavated within a grout curtain and generally horizontal boreholes drilled within the oil-bearing formations in an upward manner to enable the effect of gravity to enhance the collection of oil and also showing the drilling of horizontal holes into an overlaying oil-bearing formation for the collection of oil if sufficient driving force is present, such as natural gas, to force the oil into the shaft and thereafter into the sump.

DETAILED DESCRIPTION

The method, in accordance with the present invention, for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, is represented in FIGS. 1 and 2.

A shaft 12 may be drilled from the earth's surface 14 to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations, or strata, 16, 18 and thereafter, to a depth lower than a lowest oil-bearing formation 18 from which oil is to be collected to form a sump 20. The shaft 12 may be drilled, or excavated, in a manner well known in the art and may have a diameter suitable for the movement of personnel and equipment for the later excavation of working areas 30, 32, as will be hereinafter discussed in greater detail.

It is to be appreciated that, although only two spaced-apart oil-bearing subterranean formations, or strata, 16, 18, are shown in FIGS. 1 and 2, a greater number of such strata may be intersected by the shaft 12, as may be determined by preliminary testing and coring techniques, all well known in the art.

As the shaft 12, during excavation approaches the strata, 16, 18, a number of small diameter grout injecting holes 36, may be drilled through the strata in order to inject grout into such oil-bearing subterranean formations 16, 18, to form a grout curtain 40, 42 within and around each of the oil-bearing subterranean formations 16, 18, to prevent oil, or water, movement from the strata 16, 18, into the shaft, as it is drilled or excavated therethrough. This is more clearly shown in FIG. 2.

The grout injection also solidifies the areas between producing strata 16, 18, to insure competent rock for blasting and excavation.

Following the formation of the grout curtain, the shaft 12 is excavated through the strata 16, 18, and subsequently, the working areas 30, 32, are excavated within the grout curtains 40, 42, with each of the working areas communicating with the shaft 12. As shown in FIG. 1, the working areas 30, 32 may be generally circular in shape to facilitate the drilling of generally horizontal holes 44, 46 therefrom. Such generally horizontal holes may be in radial spaced-apart arrangements, as shown in FIG. 1.

After a working area 30, 32 has been established, equipment, including a drill 60, is lowered and the plurality of generally horizontal boreholes 46, 48, are drilled from each of the working areas 30, 32 through the grout curtains 40, 42 into the oil-bearing subterranean formations 16, 18.

As more clearly shown in FIG. 2, these horizontal holes 46, 48 may be drilled in a gradual upward direction into the strata 16, 18, if the subterranean formations 16, 18 are generally inclined in one direction away from the shaft, as is many times the case. In this manner, draining of the oil therefrom is facilitated by the effects of gravity.

It is to be understood that "horizontal" holes, within the meaning of the present description, means holes that are drilled within the oil-bearing formation 16, 18, in a longitudinal manner generally between the top and the bottom of the formation as opposed to "vertical" holes which means holes drilled in a fashion to intersect the formations 16, 18.

The boreholes 46, 48 may be thereafter lined with a perforated liner, or a short solid stand pipe, which may extend from the working areas 30, 32 into the boreholes 46, 48, a short distance, as is well known in the art, to facilitate the collection of oil therefrom. While an elaborate system of pipes and valves, along with pumps, may be provided (not shown) to connect each of the boreholes to the earth's surface 14 for the removal of oil, it is an important feature of the present invention that no such equipment is necessary.

The method of the present invention provides for the excavation of open oil collection troughs, or channels, 66, 68 in floors 72, 74 of the working areas 30, 32, generally beneath heads 80, 82 of the boreholes 46, 48, and about the perimeter of the working areas 30, 32 for the collection of oil.

The working area floors 72, 74 may be slanted toward the shaft 12 to facilitate movement of the oil thereover, or the troughs 66, 68 may be extended across the floors 72, 74 to the shaft 12 for conveying the collected oil to the shaft.

Oil so collected flows thereafter down the shaft 12, as shown by the arrows 86, 90 and is accumulated in the sump 20, forming a pool 92 of oil therein.

During excavation and drilling, sump pumps 96 may be provided to remove oil and water seeping from the working areas into the shaft to the earth's surface 14 for removal.

However, upon the completion of the shaft excavation, working excavation, and drilling of horizontal holes, the shaft 12 may be sealed, as diagrammatically shown in FIG. 2, by a seal 100 and a pipe 102 extended from the earth's surface 14 into the oil pool 92 through which the oil may be raised, or lifted, from the sump 20 to the earth's surface 14 by a single lift 98.

In addition, a valve, or outlet pipe, 104, may be provided in order to collect gas which may escape from the strata 16, 18, during the collection of oil. If gas pressure in the shaft is allowed to build, it may inhibit the flow of oil into the shaft by equalization of the driving pressure within the strata. Hence, the collection and removal of gas from the shaft 12 enables continued collection of oil as well as the production of gas.

It is apparent from the foregoing description and the figures that the method of the present invention provides a method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations 16, 18, without the use of elaborate pumps, valves and pump-

ing systems, as is normally expected in underground fluid recovery systems.

A feature of the present invention, therefore, is the recovery of oil from a plurality of spaced-apart oil-bearing formations utilizing a sealed collection system 110, as best shown in FIG. 2, thereby eliminating the ventilation requirements of the system 110, and, importantly, the need for constant safety inspections which are necessitated by the presence of men and equipment in collection systems heretofore utilized.

It should also be appreciated that generally horizontal holes 114, 116, may be drilled from one working area 32 into an overlaying working area 16, or an underlying working area (not shown) depending upon rock formation, rock mechanics and other considerations, which may depend upon the amount of oil present in the formation and the pressure gradient therein, as well as the viscosity of the oil and the porosity of the strata 16, 18.

The method for collecting oil from a plurality of spaced-apart oil-bearing formations, in accordance with the present invention, is effective, because the long generally horizontal boreholes 46, 48 have a great capture influence for collecting oil due to the great exposure of the borehole within the strata 16, 18. The method is also very efficient since a single lift system may be utilized for collection of oil from all levels, thus eliminating a multitude of pumps, valves and pipes present in theretofore developed systems for recovery of oil from underground formations.

Additionally, the method, in accordance with the present invention, is suitable for the recovery of oil from a plurality of spaced-apart oil-bearing subterranean formations from which there is little driving force causing the oil to move from within the formation.

Further, the method, in accordance with the present invention, for removing oil from a plurality of spaced-apart oil-bearing subterranean formations also may utilize the shaft and working areas as a basis for subsequent mining of the strata 16, 18, in which the strata are excavated, utilizing conventional equipment in the working areas 30, 32, and transporting the excavated material to a skip 118, supported by a rig 120, and later separating the oil from the excavated strata 16, 18, in a conventional manner.

Although there has been hereinabove-described a specific method for collecting and recovering oil and gas from a plurality of spaced-apart oil-bearing subterranean formations, in accordance with the invention, for the purposes of illustrating the manner in which the invention may be used to advantage, it should be appreciated that the invention is not limited thereto. Accordingly, any and all modifications, variations or equivalent arrangements, which may occur to those skilled in the art, should be considered to be within the scope of the invention as defined in the appended claims.

What is claimed is:

1. A method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, said method comprising the steps of:

- drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations;
- excavating a working area at selected oil-bearing subterranean formations with each said working area communicating with said shaft;
- drilling a plurality of generally horizontal boreholes from each of said working areas into the selected oil-bearing subterranean formations; and,

collecting oil from said boreholes and conducting said oil through said working areas and through said shaft to the earth's surface.

2. A method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, said method comprising the steps of:

drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations;

excavating a working area at selected oil-bearing subterranean formations with each said working area communicating with said shaft;

drilling a plurality of generally horizontal boreholes from each of said working areas into the selected oil-bearing subterranean formations; and,

collecting oil from said boreholes in each spaced-apart oil-bearing subterranean formations and raising said collected oil to the earth's surface using a single lift.

3. A method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, said method comprising the steps of:

drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations;

excavating a working area at selected oil-bearing subterranean formations with each said working area communicating with said shaft;

drilling a plurality of generally horizontal boreholes from each of said working areas into the selected oil-bearing subterranean formations;

collecting oil from said boreholes in each spaced-apart oil-bearing subterranean formations;

accumulating the collected oil from each spaced-apart oil-bearing subterranean formations; and,

raising the accumulated oil to the earth's surface.

4. A method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, said method comprising the steps of:

drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations;

injecting grout at selected oil-bearing subterranean formations to form a grout curtain within each selected oil-bearing subterranean formation, said grout curtain sealing said selected oil-bearing subterranean formation to prevent oil movement into said shaft;

excavating a working area at the selected oil-bearing subterranean formations within said grout curtain with each said working area communicating with said shaft;

drilling a plurality of generally horizontal boreholes from each of said working areas through the grout curtain and into one of the oil-bearing subterranean formations; and

collecting oil from said boreholes and conducting said oil through said working areas and through said shaft to the earth's surface.

5. The method in accordance with claim 4 further comprising the step of excavating open oil collection trough means within each said working area for collecting oil flowing from all of the generally horizontal boreholes drilled from working area and for conveying the collected oil into the shaft.

6. The method according to claims 1, 2, 3, 4 or 5, further comprising the steps of sealing said shaft during collection of oil from said boreholes.

7. A method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, said method comprising the steps of:

drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations, said shaft extending to a depth lower than a lowest oil-bearing formation from which oil is to be collected to form a sump;

injecting grout at selected oil-bearing subterranean formations to form a grout curtain within each selected oil-bearing subterranean formation, said grout curtain sealing said selected oil-bearing subterranean formations to prevent oil movement into said shaft;

excavating a working area at the selected oil-bearing subterranean formations within said grout curtain with each said working area communicating with said shaft;

drilling a plurality of generally horizontal boreholes from each of said working areas through the grout curtain and into one of the selected oil-bearing subterranean formations;

excavating open oil collection trough means within each said working area for collecting oil flowing from all of the generally horizontal boreholes drilled from each working area and for conveying the collected oil into the shaft, said oil thereafter flowing down the shaft and into the sump;

lifting oil from said sump to the earth's surface.

8. The method according to claim 7 wherein the step of drilling generally horizontal boreholes from each of said working areas comprises drilling said horizontal boreholes in a gradual upward direction into said oil-bearing subterranean formation to facilitate draining of oil therefrom by gravity.

9. The method according to claim 7 or 8 further comprising the step of sealing said shaft during lifting of oil from the sump to the earth's surface.

10. The method according to claim 9 wherein the step of excavating oil collection trough means includes excavating a channel in the floor of each working area along the perimeter of each working area.

11. A method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, said method comprising the steps of:

drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations, said shaft extending to a depth lower than a lowest oil-bearing formation from which oil is to be collected to form a sump;

injecting grout at selected oil-bearing subterranean formations to form a grout curtain within each selected oil-bearing subterranean formation, said grout curtain sealing said selected oil-bearing subterranean formation to prevent oil movement into said shaft;

excavating a working area at the selected oil-bearing subterranean formations within said grout curtain with each said working area communicating with said shaft;

drilling a plurality of generally horizontal boreholes from each of said working areas through the grout curtain and into the selected oil-bearing subterranean formations in a gradual upward direction to facilitate draining of oil therefrom by gravity;

excavating an open oil collection trough in the floor of each working area for collecting oil flowing from all of the generally horizontal boreholes drilled from each working area and for conveying the collected oil into the shaft, said oil thereafter flowing down the shaft and into the sump; sealing the shaft and working areas; and, lifting oil from said sump to the earth's surface.

12. A method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, said method comprising the steps of:

- drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations;
- excavating a working area at selected oil-bearing subterranean formations with each said working area communicating with said shaft;
- drilling a plurality of generally horizontal boreholes from each of said working areas into one of the oil-bearing subterranean formations;
- sealing said shaft;
- allowing oil to flow from said generally horizontal boreholes into the working areas and shaft; and,
- lifting oil from said shaft to the earth's surface.

13. The method in accordance with claim 12 further comprising the step of excavating open oil collection trough means within each said working area for collecting oil following from all of the generally horizontal boreholes drilled from working area and for conveying the collected oil into the shaft.

14. A method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, said method comprising the steps of:

- drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations, said shaft extending to a depth lower than a lowest oil-bearing formation from which oil is to be collected to form a sump;
- excavating a working area at selected oil-bearing subterranean formations within each said working area communicating with said shaft;
- drilling a plurality of generally horizontal boreholes from each of said working areas into the selected oil-bearing subterranean formations;
- excavating an oil collection trough within each said working area for collecting oil flowing from all of the generally horizontal boreholes drilled from each working area and for conveying the collected oil into the shaft;
- sealing said shaft to prevent air from entering said working areas and shaft;
- allowing oil to flow from said generally horizontal boreholes into the oil collections troughs and thereafter into the shaft and sump; and,
- lifting oil from said sump to the earth's surface.

15. The method according to claim 14 wherein the step of drilling generally horizontal boreholes from each of said working area comprises drilling said horizontal boreholes in a gradual upward direction into said oil-bearing subterranean formations to facilitate draining of oil therefrom by gravity.

16. The method according to claim 15 wherein the step of excavating oil collection trough within each of said working areas includes excavating a channel in the floor of each working area along the perimeter of each working area.

17. A method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, said method comprising the steps of:

- drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations;
- excavating a working area at selected oil-bearing subterranean formations with each said working area communicating with said shaft;
- drilling a plurality of generally horizontal boreholes from each of said working areas into the selected oil-bearing subterranean formations;
- collecting oil from said boreholes and conducting said oil through said working areas and through said shaft to the earth's surface;
- thereafter excavating said selected oil-bearing formations;
- lifting said excavated oil-bearing formation to the earth's surface; and,
- removing said collecting oil from said excavated oil-bearing formations.

18. A method for collecting oil from a plurality of spaced-apart oil-bearing subterranean formations, said method comprising the steps of:

- drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing subterranean formations;
- excavating a working area at selected oil-bearing subterranean formations with each said working area communicating with said shaft;
- drilling a plurality of generally horizontal boreholes from each of said working areas into the selected oil-bearing subterranean formations;
- sealing said shaft;
- allowing oil to flow from said generally horizontal boreholes into the working areas and shaft;
- lifting oil from said shaft to the earth's surface;
- opening said shaft;
- thereafter excavating said selected oil-bearing formations;
- lifting said excavated oil-bearing formation to the earth's surface; and,
- removing and collecting oil from said excavated oil-bearing formations.

19. A method for collecting oil and gas from a plurality of spaced-apart oil-and-gas-bearing subterranean formations, said method comprising the steps of:

- drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-and-gas-bearing subterranean formations, said shaft extending to a depth lower than a lowest oil-and-gas-bearing formation from which oil and gas are to be collected to form a sump;
- excavating a working area at selected oil and gas-bearing subterranean formations within each said working area communicating with said shaft;
- drilling a plurality of generally horizontal boreholes from each of said working areas into the selected oil-and-gas-bearing subterranean formations;
- excavating an oil collection trough within each said working area for collecting oil flowing from all of the generally horizontal boreholes drilled from each working area and for conveying the collected oil into the shaft;
- sealing said shaft to prevent air from entering said working areas and shaft and to collect gas from said oil-and-gas-bearing formations;

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allowing oil and gas to flow from said generally horizontal boreholes into the oil collection troughs and shaft respectively, and thereafter into the shaft and sump;

lifting oil from said sump to the earth's surface; and, removing gas from said shaft. 5

20. The method according to claim 19, wherein the step of excavating oil collection trough within each of said working areas includes excavating a channel in the floor of each working area along the perimeter of each working area. 10

21. A method for collecting oil and gas from a plurality of spaced-apart oil-and-gas-bearing subterranean formations, said method comprising the steps of: 15

drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-and-gas-bearing subterranean formations;

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excavating a working area at selected oil and gas-bearing subterranean formations with each said working area communicating with said shaft;

drilling a plurality of generally horizontal boreholes from each of said working areas into the selected oil-and-gas-bearing subterranean formations;

sealing said shaft;

allowing oil and gas to flow from said generally horizontal boreholes into the working areas and shaft;

lifting oil from said shaft to the earth's surface;

removing gas from said shaft;

opening said shaft;

thereafter excavating said selected oil-bearing formations;

lifting said excavated oil-bearing formation to the earth's surface; and,

removing and collecting oil from said excavated oil-bearing formations.

* * * * *

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OIL SANDS TECHNOLOGY &
RESEARCH AUTHORITY
Library and Information Services

United States Patent [19]

Toma et al.

[11] Patent Number: 4,532,994

[45] Date of Patent: Aug. 6, 1985

[54] WELL WITH SAND CONTROL AND STIMULANT DEFLECTOR

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[21] Appl. No.: 517,176

[22] Filed: Jul. 25, 1983

[51] Int. Cl.³ E21B 43/24

[52] U.S. Cl. 166/303; 166/30;
166/51; 166/278

[58] Field of Search 166/278, 30, 51, 303;
299/2

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Burns

[57] ABSTRACT

A well completion and method for improving the productivity of hydrocarbon emulsion from a substrate layer which holds the hydrocarbon. The well completion includes an elongated substantially horizontally disposed liner, the walls of which are perforated to receive the emulsion from the substrate. Operationally, a flow of hot stimulating fluid is injected into the productive layer in a manner to achieve optimum penetration, as well as maximum horizontal sweep thereof. A flowable dam or gravel pack is disposed at the completion remote end and serves to pass a flow of stimulating fluid whereby to achieve the desirable distribution of said stimulating medium into the substrate. However, the gravel pack deters passage of emulsion back into the liner.

7 Claims, 2 Drawing Figures

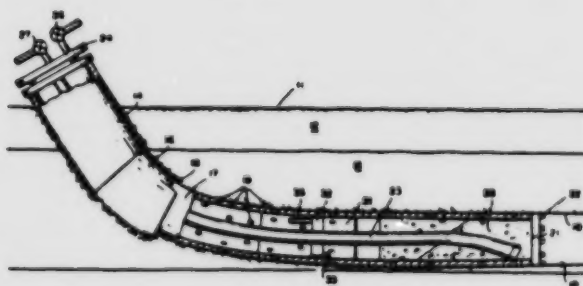


FIG. 1

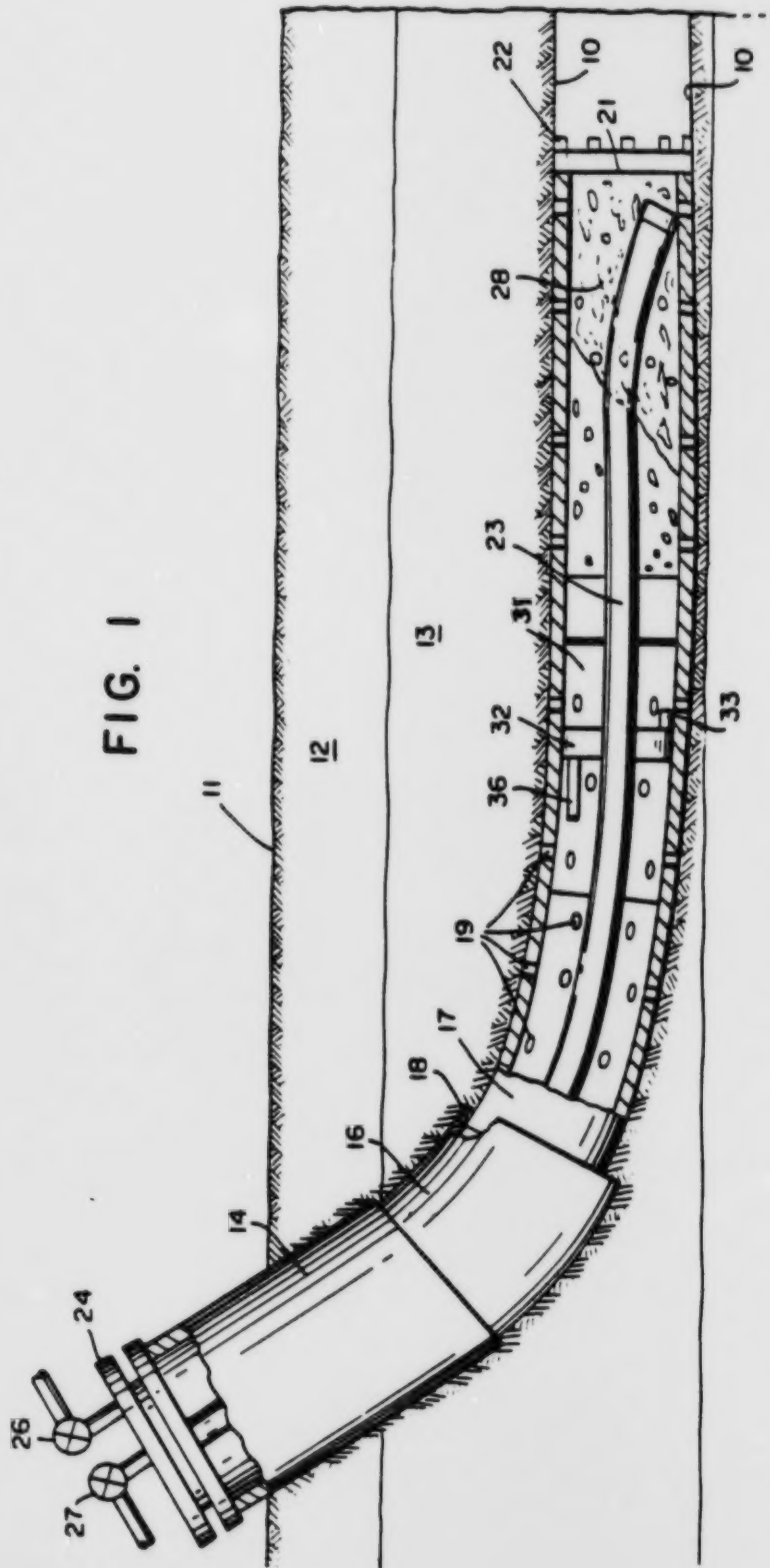
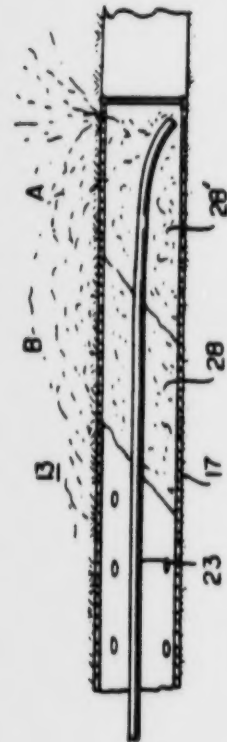


FIG. 2



WELL WITH SAND CONTROL AND STIMULANT DEFLECTOR

BACKGROUND OF THE INVENTION

This invention relates to an apparatus and method therefor, which includes the deep boring into a tar sand's formation for the purpose of extracting hydrocarbon fluids from the earth. More specifically, the invention relates to a method for treating a subterranean formation for the purpose of reducing the viscosity of fluids in the formation, thereby enhancing the extraction of said fluids. The latter is achieved through the use of means to control the movement of solids, along with the hydrocarbon emulsion, which solids would ordinarily impede the extraction process.

The vast majority of heavy oil reservoirs such as tar sands, lie 50 meters under the surface of the earth and therefore must be tapped through the use of in situ technology. Examples of heavy oil reservoirs include those located at the Athabasca and Cold Lake regions of Canada. In the United States the Edna and Siskiyew are located in California as well as in the tar sand triangle in Utah.

The high viscosity of hydrocarbon and having a density which is between 10 and 20 API, characterize all the above mentioned deposits and substantially all tar sand reservoirs. The heavy oil found in such reservoirs commonly referred to as bitumen, contained in tar sands, is usually immobile at reservoir temperatures.

The particular situation of tar sand reservoirs such as in the Athabasca region of Canada, the reservoir temperature is approximately 7° C. The viscosity of the viscous oil is above 1 million centipoises. In such a condition for all practical purposes, the hydrocarbon is considered as being formed of solid matter.

Another important feature of some tar sand reservoirs is the nature of the solid matrix which is generally comprised of a fine, unconsolidated sand with the median between 100 and 200 μ m containing the heavy, viscous oil.

Attempts to recover heavy oil from a tar sand formation have to deal with at least two major problems. These include, the reduction of the oil's viscosity, and the movement of solids such as unconsolidated sands.

One of the most successfully applied practices for recovery of the heavy oil from tar sand is the in situ heating or stimulation thereof.

The efficiency of the heating process is enhanced by the increase of net convection, or the amount of heating fluid which can penetrate the tar sand formation. As a rule, the tar sand's formation is initially saturated with an 80 to 90% high viscosity oil; only 10 to 20% saturated with gases and water.

For most of the tar sand reservoirs and particularly for ones with low and medium temperatures, an initial net convection of the heating fluids into the reservoir cannot be determined. Any increasing of the injection pressure of the heating or stimulating fluid carries with it the likelihood of fracturing the reservoir in an undesirable direction out of the tar sand formation. This circumstance is undesirable since the stimulating fluid will be of no further use.

To control the injection of heating fluids into the formation, it has been proposed to drill inclined and/or horizontally deviated wells. The latter will conduct the

heating fluids, and/or additives directly into the heavy oil formation.

The present invention provides an improvement of means for producing from tar sands. It further provides for the cooperative use of injection and production wells in a tar sand formation. Examples of such wells are disclosed in U.S. Pat. No. 3,913,672, J. C. Allen et al; U.S. Pat. No. 3,908,762, D. A. Redford. In the methods there taught, naturally occurring high permeability breaks or those formed by means of conventional hydraulic fracturing and propping are proposed as a solution for penetrating the tar sand formation.

A diversified, simultaneous injection-production method can be achieved from a single well as disclosed in U.S. Pat. No. 3,913,671, D. A. Redford et al. This latter concept is further disclosed in U.S. Pat. No. 4,088,188, R. H. Widmyer.

In the above described methods, at least one production well is completed to provide a separate path from the surface in order that a treating fluid can be introduced into a portion of an underlying hydrocarbon productive formation. The aqueous heating fluid can be injected into a portion of the formation adjacent to the production well on a timed progress basis. Thereafter, continuous injection of the aqueous heating fluid into the formation can also be utilized.

Toward the further production of heavy hydrocarbons from environments such as tar sands, there are known processes which utilize horizontal or long deviated wells to recover heavy oil from tar sands. These however are subject to at least two major drawbacks. The latter include the control of solids, and the open line bypass affect.

A significant problem is usually encountered when dealing with the production of heavy oil from an unconsolidated formation when a long, horizontal or deviated slotted liner is utilized. Briefly, when the liner penetrates clean sand or shale zones, the control of fine sand particles which are displaced during the recovery process, become a problem.

The fines removed from the formation by the injected produced fluids tend to produce permanent permeability damage by particle plugging. The particles also prompt formation of dunes when they penetrate into a screen or slotted liner.

Another problem encountered in such production relates to the control and tuning of the recovery process when a long inclined or horizontal liner is introduced in the tar sand formation. Injected produced fluids move in and out of the formation radially under the effects of a huff and puff external action and/or under the effect of condensation and flashing during thermal pumping of steam, a method referred to generally as steam stimulation.

Hot water, liquid additives and multiphase fluids that stay far from saturation, are not moved rapidly as easily as steam condensate which is near saturation. The only way to assure optimum penetration of stimulating liquids and/or gases in mixture, is by backing their injection with pressure. This mechanism is, however, less effective than flashing conduction thermal pumping.

In any tar sand substrate, the desired sweeping effect between the injection and production points along a horizontal well is reduced at a negligible fraction since the permeability to flow of an open line is usually many times higher than the permeability of the formation. Therefore, when hot fluids other than steam are injected, the formation around the previously stimulated

liner in a cyclic steam injection, is cooled down. This results since only a very small fraction of fluids will be able to penetrate the formation.

The delicate balance between flow of hot stimulating fluid, and heat transfer, will eventually further reduce the actual flow rate into the formation to a very small insignificant area around the slotted perforated liner.

It is found therefore that if the horizontal well is able to radially distribute the injected steam during the stimulation step a reasonable positive sweeping process can be maintained. The long horizontal liner will tend to allow the hot fluids to bypass, thereby overriding the formation during axial flow between the injection and producing points along the liner.

There exists therefore an unfilled need for a system which will make a long horizontal or deviated well, into a more flexible system. Further, the well should be capable of coping with the above stated solids control problem and to better control both axial, and radial inflow-outflow of fluids.

In one embodiment of the presently disclosed invention, a highly deviated, or substantially horizontal wellbore is drilled to penetrate a tar sand formation. The wellbore can extend substantially through the middle of the formation or through another appropriate point. A network of similar deviated wells of identical construction can be drilled into a tar sand field.

The particular spacing of wells and their arrangement will depend to a large degree on the size and the characteristics of the particular formation. One embodiment of the invention provides more than one well which extends through a substrate and which will penetrate the formation at an inclined alignment. Thereafter it can extend in a substantially horizontal disposition through the hydrocarbon production layer.

To overcome the aforementioned problems in producing in a tar sand environment, there is presently provided an elongated, perforated well liner which is registered within a wellbore disposed within the subterranean hydrocarbon producing layer. A well head at one end of the liner permits a pressured introduction of a stimulating fluid to the substrate.

A panel is disposed at the liner remote end wall against which a flowable dam or gravel pack can be inserted and subsequently elongated. The gravel will thus block passage of fluids through at least some of the liner's perforations.

It is an object of the invention therefore to provide an improved means and method for producing hydrocarbon fluids from a substrate that requires thermal stimulation. A further object is to provide a well completion which is capable of providing an efficient sweep of the surrounding substrate by a controlled introduction of stimulating fluid to the latter. A still further object is to provide a well completion in which a flowable, axially expandable barrier is utilized to most effectively distribute a hot stimulating fluid into the substrate whereby to provide a more efficient outflow of a hydrocarbon aqueous emulsion.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevation view in partial cross-section of a well of the type contemplated.

FIG. 2 is a schematic, segmentary view of the well shown in FIG. 1.

In achieving the foregoing objectives, there is presently provided a well completion which is used in a substrate which releasably holds a hydrocarbon fluid.

An example of the latter resides in a tar sand type of environment wherein a hydrocarbon such as bitumen is releasably held within a mass of unconsolidated sand particles.

Referring to the drawings, a wellbore 10 of the type contemplated is shown which enters the ground vertically, or preferably at an angle to the surface 11. The wellbore 10 is initially started through the overburden 12 which overlies the productive or tar sand layer 13.

Thereafter, partway through overburden layer 12, bore 10 is deviated in a manner that at least a segment of it lies in a generally horizontal relationship with respect to hydrocarbon productive layer 13, as well as to the earth's surface. Further, the well's horizontal segment is preferably positioned at a depth whereby to be adjacent to the lower border of the generally horizontal layer 13. Following the usual drilling practice, wellbore 10 is provided at its upper end with a series of casing lengths 14 and 16, which are affixed in place by cementing or other means.

An elongated well liner 17 is inserted through the respective casings 14 and 16, and is supported in casing 16 by a liner hanger 18. The latter is structured to permit passage of bitumen emulsion and/or hot stimulating fluid therethrough during the producing or the injection stages of the operation. Liner 17 can be provided at its forward or remote end with means to facilitate its being slidably inserted into and along the wall of wellbore 10.

Structurally, liner 17 comprises a steel, pipe-like member being perforated as required along that portion of its wall which lies within the tar sand layer 13. The perforations can take the form of a series of holes 19 formed through the liner wall. Alternately they can comprise slotted openings which extend either longitudinally or peripherally about the liner. Further, said perforations can be formed either before or after the liner is placed within the borehole 10.

In any event, liner openings or perforations 19 are adequate to allow the discharge of heating medium therethrough and into the adjacent tar sand containing substrate 13. Further, they allow the return flow or the entry of a hot, aqueous bitumen mixture through the same wall openings after said mixture achieves a flowable state.

In one embodiment, the forward or remote end of liner 17 is provided with a panel or plate 21 which defines a substantial barrier and partial closure to the end of the liner. Said panel means is disposed normal to the longitudinal axis of the liner and fastened in place by peripherally arranged screws, bolts, or other fastening means 22.

An elongated fluid carrying conductor or conduit 23 is disposed internally of liner 17. Said conductor can rest on the liner inner wall or it can be supported by spaced apart stabilizers which attach to the conductor.

Conductor 23 is constructed of continuous tubing or alternately of pipe lengths which are interconnected end to end. Said conduit is capable of carrying a pressurized stream of hot stimulating fluid such as steam, hot water or either of said elements having appropriate chemicals intermixed therewith to facilitate the producing process. The condition of the injected fluid will depend to a large extent on the composition of the substrate 13.

The elongated conductor 23, if supported within the liner 17 defines an annular passage 31 for at least a part of the liner length. It can, however, as noted rest di-

rectly on the conductor wall and be supported by the latter.

The upper external ends of the respective liner 17 and conductor 23 are provided with a closure means such as a well head 24. The latter includes regulating valves 26 and 27 which are operable to permit selective and controlled communication of the individual liner passages with a source of stimulating liquid.

To facilitate the efficient stimulation of layer 13 by sweeping a greater area thereof with hot stimulating fluid, liner 17 is provided with a dam or flowable gravel pack 28. Said element is disposed at the remote end of the liner in such manner that it will block a portion of the perforations which open into the substrate layer 13.

Gravel pack 28 as shown, is initially, and subsequently inserted into the well liner for predetermined lengths commencing at end panel 21 and extending toward the liner's production end. A function of this mass of gravel or other particulate material is to regulate the movement of solids from the substrate into the liner.

More specifically gravel pack 28 tends to block the passage of certain sands or fines which are displaced by the moving bitumen emulsion as the latter gravitates toward the lower pressure end of the liner. It further influences movement of stimulating fluid in layer 13.

However, it further permits a radial flow of pressurized, hot stimulating fluid into the substrate at the liner injection end. Thereafter, the gravel pack deters flow of bitumen emulsion into the liner. Thus, the flow paths A established by the stimulating fluid will tend to extend longitudinally along the liner length.

As will hereinafter be noted, after a period of operation either by the sequential thermal stimulation and drawdown process, or by simultaneous stimulation and production process, it will become apparent that the production of bitumen emulsion is decreasing. Gravel pack 28 will then be elongated by adding to the original mass, a second batch of the material 28' which is inserted through the well head 24 and into the horizontal portion of liner 17.

In a producing operation, stimulating fluids such as steam or hot water will be introduced to central conductor 23 from a connection such as valve 27, at well head 24, and the volume regulated by the well head valve. Initially, the entire well and the adjacent substrate of layer 13 are preheated to a desired temperature. This is achieved by the flow of stimulating fluid which is carried the entire length of the conductor and discharged at the remote end thereof, and by the concurrent introduction of pressurized stimulating fluid into the annular passage 31.

The hot pressurized steam will be capable of penetrating the consolidated gravel pack 28, and will pass into layer 13 through the liner perforations 19. The normal flow of such stimulant, due to its elevated temperature will be upwardly through the substrate and toward the surface.

Due to the pressure build-up in response to entry of the 300 to 400 psi steam, the latter will tend to heat the retained bitumen in layer 13, cause it to melt and thereby form passages or paths A through the layer. The interior of liner 17 will be maintained at a relatively low pressure compared to the pressure of the stimulant, the flowing bitumen emulsion will thus gravitate toward liner producing end of the liner.

Thereafter the flowing bitumen emulsion will enter the liner itself and be conducted to the surface by a pump or similar means disposed within the liner.

In one embodiment, and to add to the efficiency of the disclosed method and apparatus, the means for extracting hot bitumen emulsion from the liner, includes a pump 32 which can be movably positioned in liner 17. Said pump includes an inlet 33 which is arranged to receive the hot bitumen solution, and a pump discharge 34 which connects to a conduit 36 whereby to convey the hot emulsion to well head 24.

As gravel pack 28 is progressively added to, pump 32 can be retracted along the liner or positioned as required to effectuate the lengthening of the gravel pack as well as to remove the collected bitumen emulsion.

Operationally, the well can function on a huff and puff sequence or it can function continuously by injecting stimulating fluid as noted whereby the flow of emulsion will move toward the liner lower pressure end. In any event after a period of operation it will become apparent that the paths A which are formed in layer 13 by movement of the hot emulsion, will become depleted of bitumen. The production of product at the well head 24 will decrease and the presence of discharging steam at well head 24 will be noticeably increased. This circumstance indicates that entering stimulating fluid is no longer melting bitumen but merely adopting the easiest flow path toward the low pressure section of the liner.

At this point in the operation, and to elongate and adjust the flow paths A and B through layer 13, the internal gravel pack 28 is expanded by introducing an additional length 28' thereof. This as shown in the FIG. 3 will merely be a continuation of the original pack but positioned within the annulus 31 defined by conductor 23 and the liner 17 inner wall such that a greater number of the liner perforations 19 will be covered.

With the extended gravel pack 28 and 28' in place, the introduction of pressurized stimulating steam through the central conductor is continued. The latter will enter substrate layer 13, and rather than following the (A) paths previously formed by the stimulating injection, will be forced to adopt a new set of paths (B) such that the melted bitumen which is unable to enter the liner 17 through the previous perforations, will be forced to enter perforations closer to well head 24.

Thereafter as the flow of stimulant is continued into the substrate, the new paths B formed therethrough will allow the bitumen emulsion access to liner 17, which bitumen has been extracted from an area of layer 13 that has not been heretofore stimulated.

Over a period of time as the producing operation is continued, gravel pack 28 is progressively extended. Eventually the latter will approach the upper level of the productive layer 13 so that further stimulation will not add to the volume of emulsion produced.

To function effectively, the sizes of the agglomerated particles which make up gravel pack 28 are such that the majority of the gravel particles will not pass through perforations 19 in the liner wall. Thus, the respective gravel pack extensions commencing with extension 28', are introduced sequentially to the liner by way of well head 24 in the form of a slurry, a gel or the like.

Preferably the gravel slurry is carried through liner 17 in a slug such that it will abut, and form extension 28' to the previously positioned pack 28. Excessive fluid which carries the slurry slag will pass through perforation 19 into the adjacent substrate, this flammable carrier

material can also be pumped from the liner as it accumulates.

It is understood that although modifications and variations of the invention can be made without departing from the spirit and scope thereof, only such limitations should be imposed as are indicated in the appended claims.

We claim:

1. A well completion for producing hydrocarbons from a tar sand layer comprised of unconsolidated sand particles in which the hydrocarbon is releasably held, which well completion is registered within a wellbore disposed in a generally horizontal disposition along said tar sand layer, and including;
 - an elongated well liner having a perforated wall which is capable of transmitting a stream of hot stimulating fluid in one direction therethrough to penetrate said tar sand layer, and a flow of hydrocarbon emulsion together with unconsolidated sand particles in a reverse direction through the wall and into the liner,
 - a well head at the upper end of said elongated well liner, and a transverse panel at the liner remote end forming at least a partial closure thereto,
 - a conductor depending from said well head and extending longitudinally of said liner and terminating in a discharge port adjacent to said panel, and means forming a longitudinally extendable gravel pack comprised of a mass of unconsolidated particulate matter disposed at the liner remote end to substantially cover at least some of the perforations therein and to deter inward flow of hydrocarbon emulsion and unconsolidated particulate matter into the liner through said covered perforations.
2. In a well completion as defined in claim 1, wherein said means forming said gravel pack includes;
 - an annular mass which extends from said transverse panel in a direction toward the well head.
3. In a well completion as defined in claim 1, wherein said means forming said gravel pack includes;

a mass of unconsolidated earthen material which is pervious to the flow of the stimulating fluid.

4. In a well completion as defined in claim 1, wherein said flowable mass of said particulate matter is comprised primarily of particles having a size which is incapable of passing through the liner wall perforations.

5. In a well completion as defined in claim 1, including a pump means disposed in said liner adjacent to the gravel pack.

6. Method for producing bitumen emulsion by thermal stimulation of a subterranean formation comprised of a tar sand layer, which method includes the steps of; forming a wellbore having a portion which extends through said tar sand layer in a generally horizontal direction,

inserting a perforated wall well liner having a remote end and production end, into the wellbore, said liner including a conductor which extends substantially the length thereof and is adapted to communicate with a pressurized source of a thermal stimulating fluid,

forming a gravel pack in the said liner remote end to define an unconsolidated mass of particulate matter which covers a portion of the liner wall perforations for a predetermined distance extending from the liner remote end toward the production end thereof to prevent the flow of hydrocarbon emulsion into the liner through said covered portion of the perforations,

introducing a stream of said thermal stimulating fluid by way of said conductor into the substrate adjacent to said well liner whereby to establish a flowable bitumen emulsion,

and recovering said bitumen emulsion from the well liner production end.

7. In the method as defined in claim 6, including; the step of introducing additional particulate matter to said liner to extend the gravel pack length toward the production end thereof, whereby to cover additional liner perforations and cause said bitumen emulsion to enter only uncovered perforations at the liner production end.

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(19) (CA) **CANADIAN PATENT** (12)

(54) Method of Assisting Surface Lift of Heated Subsurface
Viscous Petroleum

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(73) Granted to Chevron Research Company
U.S.A.

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(22) FILED 830608

(30) PRIORITY DATE U.S.A. (413,326) 820831

No. OF CLAIMS 5

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METHOD OF ASSISTING SURFACE LIFT OF
HEATED SUBSURFACE VISCOUS PETROLEUM

05

BACKGROUND OF THE INVENTION

This invention relates to recovering viscous petroleum from petroleum-containing formations. Throughout the world there are many deposits of high-viscosity crude petroleum in subsurface formations; some of these deposits are referred to as oil sands. In general, the crude petroleum in these deposits is not recoverable in its natural state through a well by ordinary production methods because there is insufficient or non-existent natural drive mechanisms to cause the petroleum to flow into a well.

There have been many in-situ well-to-well pilots proposed for shallow deposits of oil sands, all of which used some form of thermal stimulation after establishing communication between an injector well and a producer well. Many processes have been utilized in attempting to recover viscous petroleum from viscous oil formations of the Athabasca Tar Sands type, including the application of heat to such viscous petroleum formations by steam or underground combustion. The use of vertical slotted liners positioned in the viscous oil formation as a conduit for hot injection fluids has also been suggested; however, most of these methods have not been overly successful because of the difficulty of establishing and maintaining communication between an injector well and a producer well. Clearly, if one could eliminate the need to establish and maintain communication between an injector well and a producer well, regardless of the drive fluid or recovery technique employed, many of these viscous petroleum deposits could become potentially successful projects. Further, techniques are needed to assist in lifting the produced viscous petroleum to the wellhead and for clearing from the well formation solids produced with the viscous petroleum.

40

BRIEF DESCRIPTION OF THE INVENTION

05 The present invention is directed to a method of assisting the recovery of viscous petroleum from a petroleum-containing formation and is particularly useful in those formations where communication between an injector and a producer is difficult to establish and maintain. A hole is formed through the petroleum-containing formation and a generally horizontal, tubular pair of concentric conductors is inserted into the hole to provide a continuous, uninterrupted flow path from the wellhead through the generally horizontal tubular members in the formation and back to the wellhead. A hot fluid is flowed through the inner tubular member, returning to the surface via the annulus to heat viscous petroleum in the formation outside the outer tubular member to reduce the viscosity of at least a portion of the petroleum adjacent the outside of the outer tubular member with the intention of establishing a potential passage for fluid flow through the formation adjacent the outside of the tubular member. Alternatively, the hot fluid flow may be reversed by injecting down the annulus and returning to the surface through the inner tubular member.

25 The outer conductor of the tubular member may initially be perforated in the zone where recovery of the viscous petroleum is desired or the tubular member may be subsequently perforated to provide passage ways between the formation and the tubular member.

30 After the viscous petroleum has been heated to become mobile, the lower portion of the tubular member is isolated from the fluid flow and opened to production of the heated petroleum. A diverter, for example, a movable packer, is placed within the tubular member between the inner and outer conductor to cause the hot fluid to pass out through the perforations into the formation, there acting as a drive fluid to force the heated petroleum toward the isolated open portion of the tubular member. In most cases the initial placement of the packer will be near the most downhole end of the well bore in order to

05 maximize the pressure gradient between drive fluid and the
formation, thereby facilitating early communication and
petroleum production. The ratio of produced petroleum to
drive fluid is monitored at the wellhead to recognize an
indication of excessive pass-through of the drive fluid
and, based on the monitored ratio, the diverter is moved
10 within the tubular member to optimize the petroleum
production rate and to minimize the drive fluid pass-
through.

The diverter may be attached to the inner con-
ductor to be movable back and forth within the outer
tubing to maximize both the heating of the formation and
15 the movement of the heated viscous petroleum into the
producer well. In the event of an unwanted breakthrough
of the drive fluid through the formation into the produc-
ing portion of the well, the diverter can be moved to
another location within the tubular member so as to main-
20 tain a desired formation heating and petroleum movement as
the breakthrough heals.

A third hollow conductor is placed within the
inner conductor to provide a path for circulating carrier
fluid for the produced petroleum and drive fluid. The
25 third hollow conductor may also be rotatable to provide
for clean-out operations within the tubular member thus
avoiding blockage of the tubular member with produced sand
and formation particles moved with the produced petroleum.

30 In the preferred form, the hot fluid which is
flowed through the tubular member is steam, and the drive
fluid used to promote movement of the petroleum is also
steam. Under other conditions, the hot fluid and the
drive fluid may be injected intermittently. The injec-
35 tivity of the drive fluid into the formation is controlled
to some extent by adjusting the condition of the hot fluid
flowing through the tubular member. In this manner, the
sweep efficiency of the drive fluid in the formation may
be improved.

OBJECT OF THE INVENTION

05 An object of the invention is a method for producing viscous petroleum from a subsurface petroleum-containing formation using a single substantially horizontal well bore passing through the formation.

10 A further object of the present invention, in accord with the preceding object, is a method for heating, moving and producing viscous petroleum in a subsurface petroleum-containing formation using a concentric tubing well element within a well bore passing through the formation.

15 Another object of the present invention, in accord with the preceding objects, is an apparatus for use in a well bore passing through a formation containing viscous petroleum.

20 Further objects and features of the present invention will be readily apparent to those skilled in the art from the appended drawings and specification illustrating a preferred embodiment wherein:

FIG. 1 is an elevational view, partially in section, illustrating one form of assembled apparatus.

25 FIG. 2 is a cross-sectional view through a subsurface earth formation illustrating injection, production, and lifting paths in accord with the method of the present invention.

30 FIG. 3 is a cross-sectional view similar to FIG. 2 and illustrating a method of operation in accord with the present invention in a manner to remove particulate material from the subsurface well bore.

DETAILED DESCRIPTION OF THE EMBODIMENTS OF THE INVENTION

35 Referring now to the drawings, and to FIG. 1 in particular, where the preferred embodiment of apparatus assembled in accordance with the invention is illustrated, FIG. 1 shows a well 10 drilled into an earth formation 11 having an overburden 12, an impervious layer 14 and a subsurface zone 16 containing viscous petroleum such as a tar sand. The well 10 includes an outer casing 13
40 cemented or completed to the formation overburden 12 and

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05 an inner casing 22 cemented to the outer casing 18. A
first tubular conductor or producing string 24 is placed
within the inner casing to provide a first hollow
communication channel to the subsurface formations. A
second tubular conductor or injection string 26 is placed
10 within the first tubular conductor 24 to provide a second
hollow communication shaft to the subsurface formations
and to establish an annular space 28 between the first
tubular conductor 24 and the second tubular conductor
26. Both the first and second tubular conductors are
centralized within the well by suitable centralizers 32.
15 At the downhole end of the well, the inner casing 22 is
perforated at 34 in a series of places and a packer 36 is
provided between the inside of the inner casing 22 and the
outside of the first tubular conductor 24 in the annulus
between these two members.

20 The bottom hole end of the inner casing 22 is
completed with a cement plug 38 or other means for closing
the end of the well. The bottom hole end of the second
tubular conductor 26 is completed with a rotatable
agitator or fishtail drill bit 42 which is adapted to be
25 rotatable within the perforated inner casing 22 below the
packer 36 and above the plug 38.

As illustrated in FIG. 1 the downhole end of the
well 10 is deviated toward the horizontal to provide
access to a larger horizontal portion of the zone 16 and
to expose the formation surrounding the well to the heat
30 from the fluids transported through the well and into the
formation.

At the earth's surface the well is supplied with
a wellhead 52 completing the outer casing 18 and the
exterior of the inner casing 22. The wellhead is provided
35 with a cap 54 permitting both rotational and longitudinal
movement of the first tubular member 24, and the second
tubular member 26 within that first tubular member, so
that the concentric inner string of the two tubular mem-
bers can be both rotated and inserted or withdrawn from
40 the subsurface well. Below the cap 54 at the wellhead 52

05 a connection is made from a fluid drive source 56 through a conductor 58 to the annulus 62 between the inner casing and the tubular member 24.

10 The upper end of the first tubular conductor 24 is completed with a second cap 64 which provides for rotary and longitudinal movement of the tubular conductor 26. The cap 64 also provides a fluid communication
15 channel through conductor 66 from the annulus 28 between the first and second tubular conductors and is adapted to introduce rotational drive to the first tubular conductor 24 through shaft 68 from rotary drive 72. The position of the inner conductor 26 within the well is controlled by
20 mechanism 74 which contains a reel 76 onto which the tubing 26 may be reeled and a means for injecting carrier fluid. The production of fluid through the conductor 66 is monitored by production monitor 78 to provide communications to the mechanism 74 through mechanical or electrical connection 82.

25 The movable portions of the wellhead are supported on a derrick 84 having suitable elevation control mechanisms 86 for raising or lowering the tubular members into and out of the well.

30 FIGS. 2 and 3 provide an enlarged view of the subsurface, and generally horizontal, portion of the well 10 in the subsurface zone 16. The packer 36 is movable with the first tubular conductor 24 into and out of the well independently of the second tubular conductor 26. In the same respect, the second tubular conductor is movable independently into and out of the well, below the packer 36 and above the plug 38. The inner tubular conductor 26 is rotatable to agitate materials within the well and
35 below the packer 36 should such materials be produced with the fluid that moves into the perforations 34.

40 The apparatus illustrated in FIGS. 1 through 3 is adapted to complete the subsurface well and to be useful in the performance of the method of the present invention. It should be understood that other forms of apparatus to accomplish the same purposes are contemplated

in accordance with the present disclosure. The apparatus
itself permits the method of the present invention to be
performed within the subsurface formations where viscous
petroleum and/or tar sands may be produced if the petroleum
deposits may be heated to increase their viscosity to
permit them to flow through the formations and into the
perforations of the well bore. For that purpose, the well
construction and surface equipment of the present invention
is adapted to provide for the flow of a drive fluid
down through the annulus 62 in the path of the arrow
generally shown at 100 and out the perforations 34 to
accomplish heating of the formation 16 in the areas near,
to and surrounding the well bore. As the formation
petroleum is heated, it is moved by the drive fluids
passing out through the perforations 34 to establish production
of the mobile petroleum generally along the arrows
102 into the perforated inner casing 22 below the packer
36 and into the annulus space 28 between the inside of the
first tubular conductor 24 and the second tubular conductor
26. Because the viscous petroleum still is under
little subsurface pressure, it will probably not flow to
the surface under its own pressure, and, for that reason a
carrier fluid is pumped down the inside of the second
tubular conductor 26 and out through the bottom hole end
of that conductor, as shown by arrows 104, to mix with the
produced petroleum to force the mixture of the carrier
fluid 104 and production 102 up through the annulus 28.
At the wellhead the produced carrier fluid and viscous
petroleum are monitored by the production monitor 72 with
the production going to a pipeline or storage system and,
if possible, the separated carrier fluid being returned to
the injector system 74.

The production monitor 78 is adapted to analyze
the produced fluid to determine when excessive pusher
fluid 100 is passing in through the perforations at the
downhole end of the well, as well as sensing the quantity
of carrier fluid being produced at the surface. From that
analysis it is possible to determine whether the drive

fluid has begun to breakthrough the formation. If breakthrough occurs, the packer 36 is moved to another location along the well bore to cause the drive fluid to be injected into formations where the viscous petroleum has been heated to a mobile form thus forcing the produced fluids into the perforations at the lower end of the well and to maximize the production of viscous petroleum without excessive amounts of pusher fluid.

The subsurface apparatus is provided with the agitator or fishtail drill bit 42 to provide a means for removing the produced subsurface formation materials which may have passed through the perforations 34 along with the viscous petroleum. It has been known, particularly in the case of the tar sands, that the sand material is produced with the formation petroleum and that, as the sands are deposited within the subsurface well, the well becomes clogged and the petroleum can no longer be produced through the well. For the purpose of removing such formation materials, the drill bit 42 is placed at the downhole end of the second tubular conductor 26 and is adapted to be rotated within the first tubular conductor 24 to agitate the material which may have been deposited in the well bore. At the same time the carrier fluid can be injected through the inner conductor 26 to carry this formation sand or other materials to the earth surface for removal from the well.

One suitable method for accomplishing the removal of sands from the formation is to inject through the inner conductor 26 a stabilized foam. Such foam has superior lifting qualities for carrying the subsurface formation materials to the earth surface. The process of accomplishing that removal is described in U.S. Patent No. 3,583,483, issued in the name of Robert W. Foot, for Method For Using Foam In Wells and assigned to the same assignee as the present application.

While certain preferred embodiments of the invention have been specifically disclosed, it should be understood that the invention is not limited thereto as

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many variations will be readily apparent to those skilled
in the art and the invention is to be given its broadest
possible interpretation within the terms of the following
claims.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

05

1. A method for assisting the recovery of viscous
petroleum from a subsurface petroleum-containing zone
comprising:

10

(a) directionally drilling a well from the earth's
surface into said subsurface petroleum-containing zone to
position said well within said zone in a generally hori-
zontal position;

15

(b) casing said well and perforating said casing at
least in said generally horizontal portion thereof;

20

(c) placing a first tubular conductor within said
casing and positioning the downhole end of said first
tubular conductor adjacent to said perforations in said
casing in said petroleum-containing zone nearest to the
earth's surface end of said casing;

25

(d) injecting hot fluid through said first tubular
member into said perforated casing so as to heat said
viscous petroleum adjacent to said perforate casing and to
increase the mobility of said viscous petroleum to cause
said heated viscous petroleum to flow into said casing
through said perforations therein;

30

(e) placing a second tubular conductor within said
first tubular conductor and positioning the downhole end
of said second tubular conductor generally adjacent to the
downhole end of said casing;

35

(f) injecting a carrier fluid through said second
tubular conductor to flow up said casing to the earth's
surface in the annular space between the inside of said
casing and the outside of said first tubular conductor,
said flowing carrier fluid carrying said heated viscous
petroleum to the earth surface.

40

2. The method of Claim 1 with the additional steps
of monitoring said flowing carrier fluid and said produced
viscous petroleum and controlling the flow of said carrier
fluid through said second tubular member to maximize the
production of said viscous petroleum.

65 3. The method of Claim 2 with the additional step of
positioning said downhole end of said first tubular member
adjacent to other perforations in said casing closer to
the downhole end of said casing in accordance with the
monitored production of said carrier fluid and said pro-
duced heated viscous petroleum.
10

15 4. The method of Claim 3 with the additional step of
attaching a means to the downhole end of said first tubu-
lar member and rotating said first tubular member while
moving said first tubular member within said casing adja-
cent to said perforations therein to loosen any subsurface
materials produced through said perforations, and flowing
said loosened subsurface materials to the earth's surface
through said casing.
20

25 5. The method of Claim 4 with the additional step of
passing a foamed fluid through said second tubular member
to carry subsurface materials produced through said perfo-
rations in said casing to the earth's surface.

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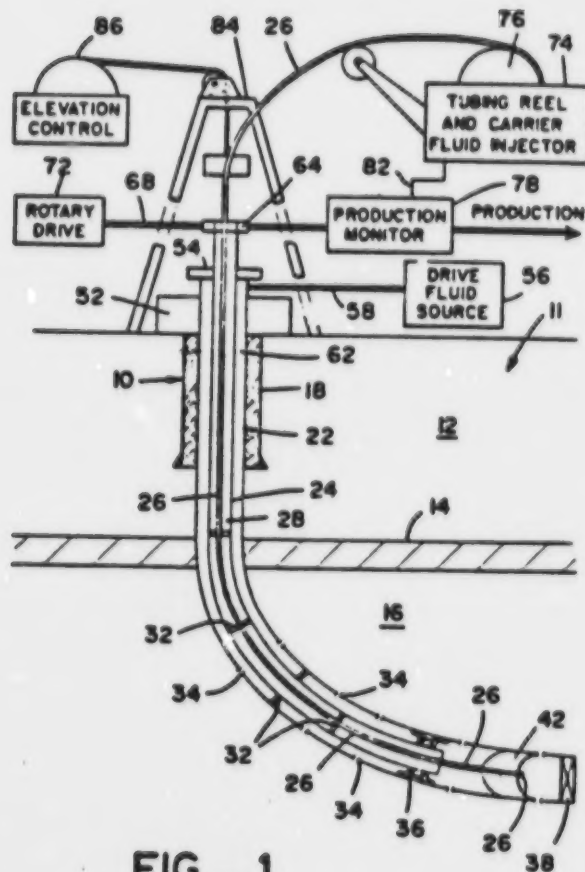


FIG - 1

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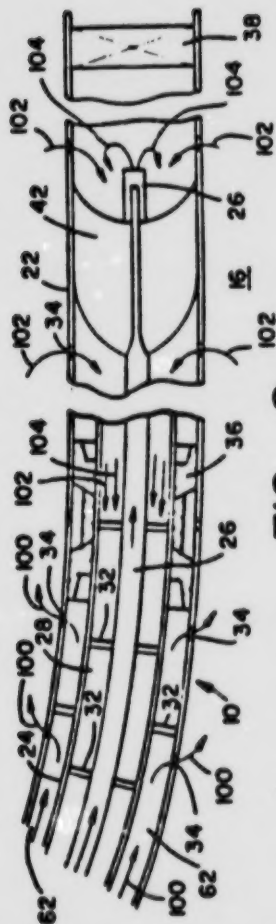


FIG - 2

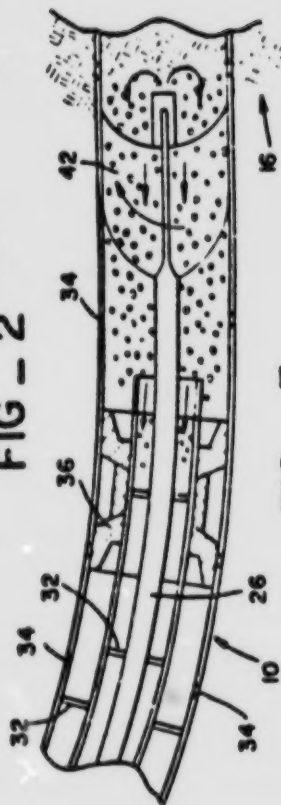


FIG - 3

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Alberta
OIL SANDS TECHNOLOGY &
RESEARCH AUTHORITY
Library and Information Services

United States Patent [19]

Brown et al.

[11] Patent Number: **4,535,845**[45] Date of Patent: **Aug. 20, 1985**[54] **METHOD FOR PRODUCING VISCOUS HYDROCARBONS FROM DISCRETE SEGMENTS OF A SUBTERRANEAN LAYER**[75] Inventors: **Alfred Brown; Wann-Sheng Huang; Yick-Mow Shum**, all of Houston, Tex.[73] Assignee: **Texaco Inc.**, White Plains, N.Y.[21] Appl. No.: **528,672**[22] Filed: **Sep. 1, 1983**[51] Int. Cl.³ **E21B 43/24**[52] U.S. Cl. **166/272; 166/252**[58] Field of Search **166/30, 245, 252, 271-274, 166/263**[56] **References Cited****U.S. PATENT DOCUMENTS**

4,390,067	6/1983	Willman	166/272
4,434,849	3/1984	Allen	166/272

Primary Examiner—Stephen J. Novosad

Assistant Examiner—William P. Neuder
Attorney, Agent, or Firm—Robert A. Kulason; Robert B. Burns

[57] **ABSTRACT**

Method for producing viscous hydrocarbon products such as heavy crude oil or bitumen from tar sands, which products must be thermally converted into flowable condition. A discrete vertical subsection of a productive subterranean layer is margined by a pair of spaced apart vertical wells and a horizontal well that lies substantially horizontal to the vertical wells. Controlled, pressurized flows of a heating medium such as steam are introduced to one of the vertical wells and to the horizontal well, whereby to establish a controlled thermal front. The latter is progressively urged by the pressurized steam, through the discrete vertical subsection and toward the other of the vertical wells at which hydrocarbon emulsion is produced.

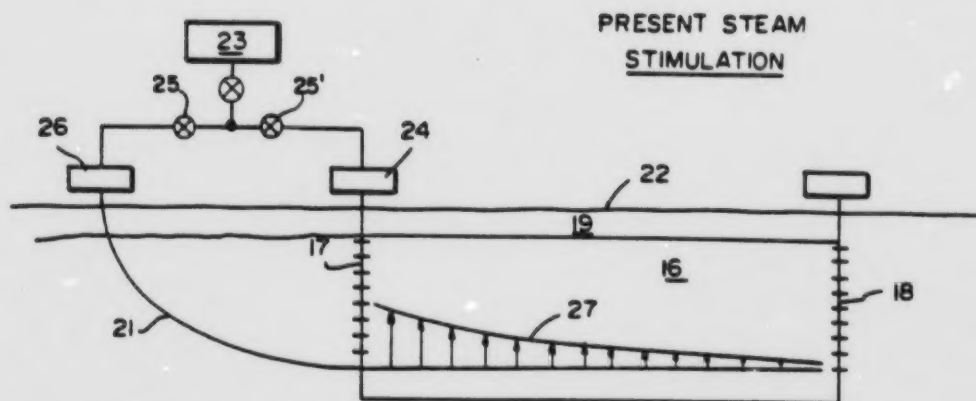
2 Claims, 7 Drawing Figures

FIG. 1

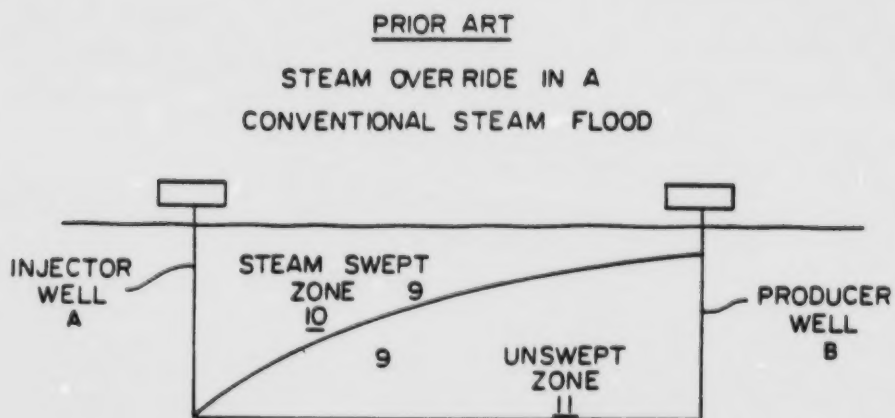


FIG. 2

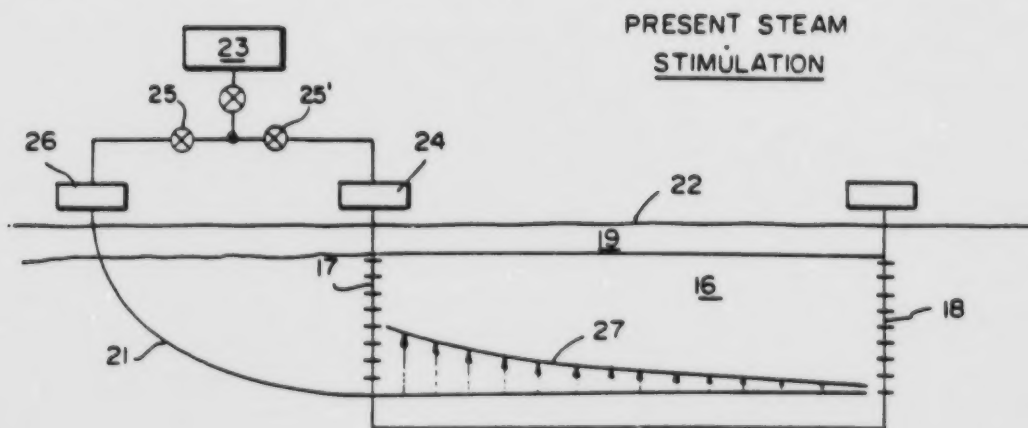


FIG. 3

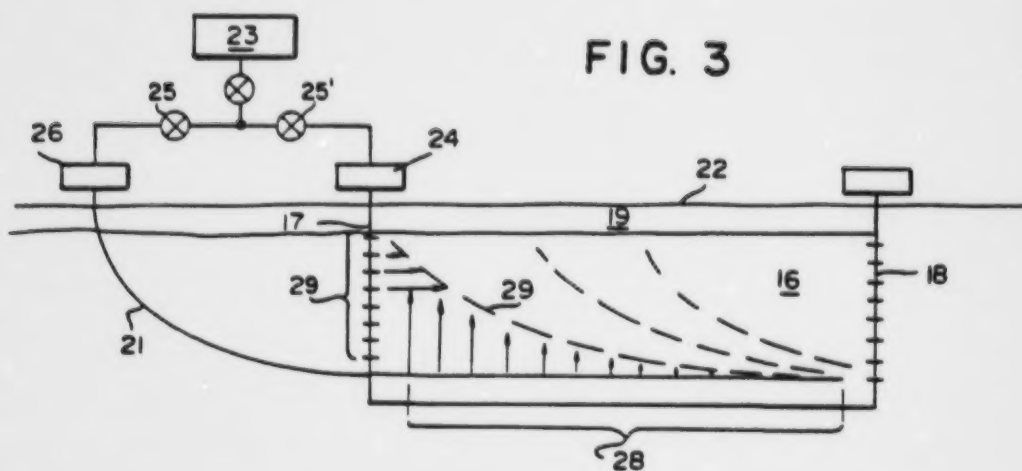


FIG. 4

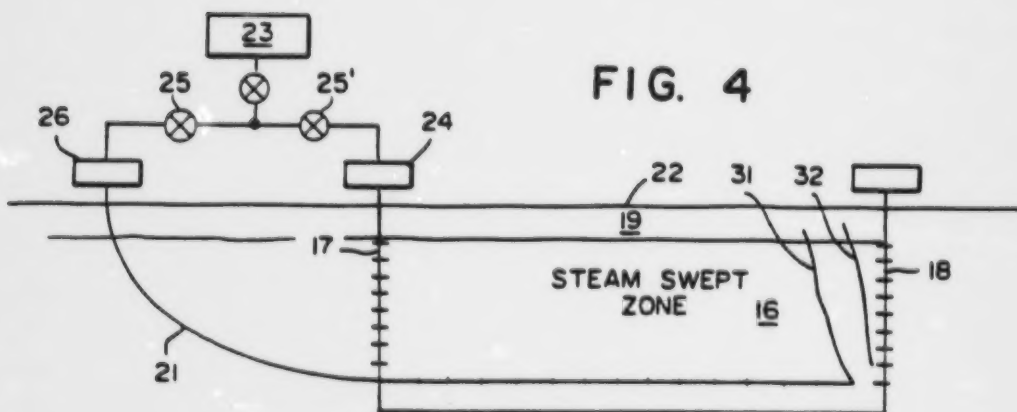


FIG. 5

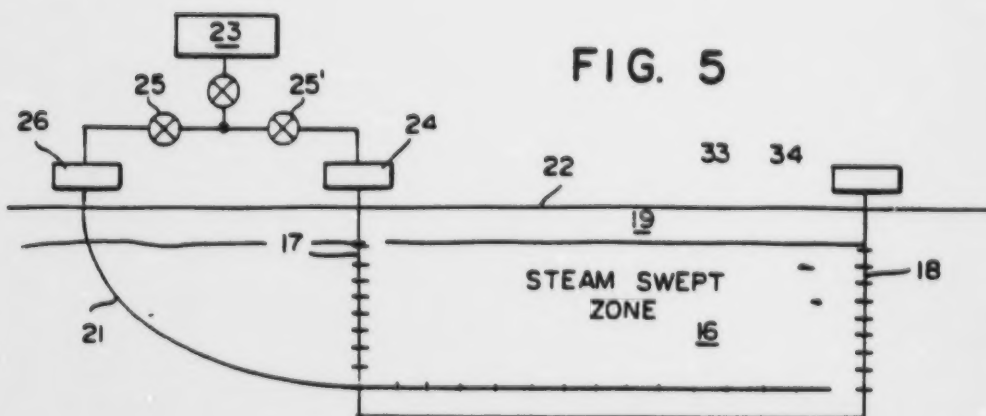
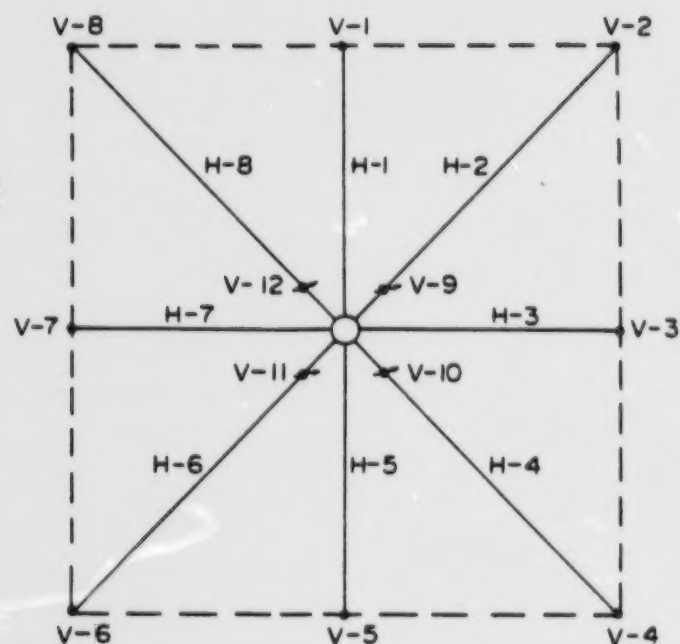
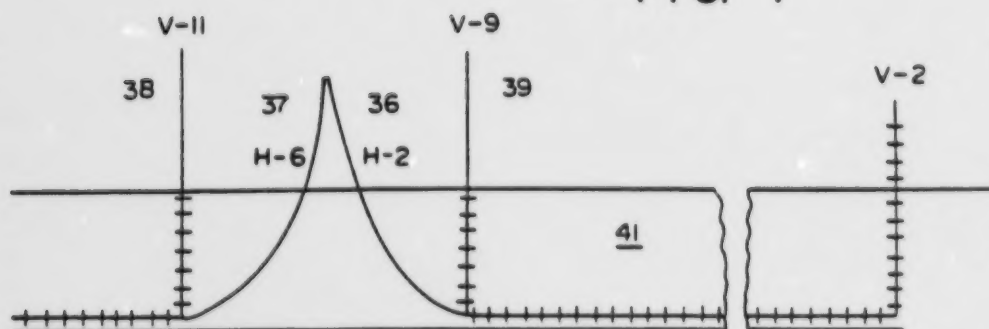


FIG. 6



- Legends:
- VERTICAL INJECTION WELLS
 - VERTICAL PRODUCTION WELLS
 - H-1, H-8 HORIZONTAL WELLS
 - HORIZONTAL WELL PAD
 - — PATTERN BOUNDARY

FIG. 7



METHOD FOR PRODUCING VISCOUS HYDROCARBONS FROM DISCRETE SEGMENTS OF A SUBTERRANEAN LAYER

BACKGROUND OF THE INVENTION

The production of viscous hydrocarbons and bitumen from tar sands, is not readily achieved without some form of production enhancement. Among the most widely utilized of the enhancement steps is to thermally treat the productive layer thereby to encourage the rate of production. This form of enhancement normally constitutes the introduction of a heating medium, usually hot water or steam, directly into the substrate.

The effects of this introduction of pressurized heating medium is two-fold. Firstly the elevated temperature heats the hydrocarbon product to increase its mobility, or stated otherwise, to decrease its viscosity. Secondly, the presence of the pressurized heating media within a substrate tends to force the movable hydrocarbon toward a lower pressure zone. The latter is normally established by the positioning of a producing well, in such a location within the substrate as to receive the pressurized flow.

In one of the most commonly practiced methods of this enhanced recovery procedure, pressurized steam, functioning as the heating medium is introduced or flooded into a single well whereby to be discharged through perforations in the latter and into the substrate. The heated and flowable hydrocarbon emulsion is caused to move toward the producing well.

Rather than producing from a remotely positioned well, the huff and puff method can be utilized. In the latter, a single well is provided with a heating medium such as steam, to establish a heated environment. Thereafter the well is closed in to permit the heat to penetrate into a wider area of the substrate. Subsequently, the well is activated to produce the now flowable hydrocarbon or bitumen therefrom.

In any steam flood or thermally stimulated operation, because the steam enters at a high temperature and under substantial pressure there will be a natural propensity for it to rise through the earthen productive layer. The rate of rise will depend on the composition of the substrate and on the length of time to which it is subjected to the pressurized injection of heating medium.

In either event, the heating medium will eventually cause the hydrocarbon flow to break through the substrate and into a producing well. Logically, the heating medium will tend to follow the path of least resistance through the substrate. Thus, it will establish the necessary heating step which gradually liquefies the retained bitumen or viscous petroleum.

The composition of the substrate will be a major factor in determining the effect of the injected steam and its passage through the productive layer. As noted, the steam will tend to rise through the productive layer while contacting the viscous hydrocarbon.

Over a period of time, this continued pressurized introduction of heating medium will cause the steam to override a portion of the hydrocarbon containing layer and move directly to the producing well. The result of such action is that a considerable portion of the productive layer is completely bypassed. The hydrocarbon held therein will remain unheated and in place since its condition is not affected by the steam.

Toward overcoming or obviating this presence of an unproductive hydrocarbon layer in the midst of a highly productive area, the present method is disclosed. Specifically, the function of the heating and stimulating medium is maximized by introducing it directionally into a limited area. Thus, a substantially vertical subsection of the substrate layer is segregated by a series of wells which tend to marginate said subsection. These wells are comprised of at least two horizontally spaced and vertically disposed wells. In addition, one third well is positioned to extend in a substantially horizontal direction passing adjacent to the bottoms of the respective vertical wells.

By the controlled introduction of the heating medium, such as steam into two of these wells, a thermal front can be established in the segregated subsection. This front, by virtue of the pressurized heating medium, is caused to advance laterally through the productive layer.

It is therefore an object of the invention to provide an enhanced recovery technique for producing viscous hydrocarbon products which must first be put into flowable condition before being produced. Another object is to provide a method for producing viscous hydrocarbons or bitumen from a tar sand formation by the controlled introduction of a heating medium into the productive layer. Still another object of the invention is to provide a method for producing viscous hydrocarbon products from a subterranean layer by establishing a thermal front within the layer which advances horizontally toward a producing well.

DESCRIPTION OF THE DRAWINGS

The various figures included herewith graphically represent an elevation, cross-sectional view through a hydrocarbon containing substrate.

FIG. 1 represents a substrate in which spaced apart injection and producing wells A and B are inserted, and into which substrate a pressurized flow of steam is introduced by way of the injection well A. The production of hydrocarbon product takes place through well B.

FIGS. 2 through 5 illustrate a hydrocarbon producing substrate into which two vertical wells, as well as a horizontal well have been inserted. The wells are arranged to thermally stimulate and produce hydrocarbons from a limited area.

FIGS. 6 and 7 illustrate a pattern of wells in which the novel method can be practiced.

Referring to the drawings, FIG. 1 illustrates a cross-sectional elevation view of a hydrocarbon holding layer L which is subjected to an enhanced oil recovery treatment. Production of the contained hydrocarbon is stimulated by the introduction of a pressurized flow of a hot stimulating fluid such as steam into the single vertical well A.

Such wells as here contemplated are perforated along the length thereof which lies in the productive layer L. Thus, injection of steam or other thermal stimulating fluid into the substrate will occur along the entire length of the injection well.

Since the stimulating steam will tend to rise through the productive layer, over a period of time the steam front and consequently the heated area of the substrate will progress toward producing well B. Concurrently, however, the hot steam will rise toward the upper layer of the productive substrate.

As shown in FIG. 1, the overall result of this action will be that only part 10 of the productive layer L is

swept by the stimulating steam. The remaining segment 11, which is remote from injection well A, will remain substantially unswept. To all intents, the hydrocarbons in this unswept area 11 will remain viscous and thus unproduced.

Referring to FIG. 2, and according to the invention, a more complete draining, and fuller utilization of a particular hydrocarbon producing substrate 16 can be realized. This is achieved by in effect segregating the productive layer 16 into discrete vertical subsections. Thereafter, by controlled and selective introduction of stimulating steam into the subsection, the capability and potential of the injected steam will be utilized to its greatest capacity.

The economic affect of the disclosed method will result in a more efficient use of the productive substrate and further. Further, the method will yield a greatly reduced cost per barrel of hydrocarbon product produced.

As shown in FIG. 2, the particular subsection 16 of the hydrocarbon containing layer, is enclosed or marginated within a basic pattern of three wells.

The productive subsection from which the hydrocarbon will be extracted can lie immediately beneath the surface. Quite often, however, hydrocarbon containing layers of this type are found between, and bounded by non-productive layers. Productive layers are also found in different thicknesses, some being quite thin while others are found to be several hundred feet in thickness.

For the instant disclosure, and with no intention of limiting the scope of the claimed subject matter, the method hereinafter will be described with respect to production of a tar sand layer which lies beneath an overburden of a non-hydrocarbon productive earthen layer. Also, a number of heating mediums can be utilized to achieve the desired stimulation of the viscous hydrocarbon. The novel method will however be hereinafter described for convenience with respect to injection of pressurized steam of varying quality.

In a preferred embodiment of a pattern of wells which are positioned to achieve the instant objectives, at least three wells are formed into a subterranean productive subsection. These wells are positioned in a manner to in effect generally marginate the three borders of the limited area to be selectively produced. The respective wells include two, 17 and 18, which penetrate overburden 19 at a substantially vertical alignment. Said wells bottom out adjacent to the lower end of the tar sand layer.

These two spaced apart wells 17 and 18 are generally aligned in the normal or upright, vertical position. The third well 21, however, is preferably commenced in a vertical or slanted alignment at the surface 22 to initially penetrate overburden 19. Thereafter, said third well, after entering the tar sand layer is in a substantially horizontal position.

Well 21 can be diverted from its vertical or slanted alignment as it progresses deeper through overburden 19. It is then diverted into its horizontal position toward or adjacent to the lower end of said productive layer 16. It is then continued in a horizontal position along the lower side of said layer.

All of the well casings utilized in the horizontal as well as the vertical wells, are at least partially perforated. The perforations can be pre-made prior to the well casing being inserted into a well bore, or subsequent to insertion of the casing. In either instance, the perforated portions of the casing will lie within the tar

sand layer to best function in a manner to inject steam into the substrate and/or to receive the flowing hydrocarbon emulsion therefrom.

In the normal manner, for carrying out a steam flood operation, steam is received from a source 23 such as a steam generator disposed relatively close to the various well heads 24 and 26. Suitable valve connections 25 and 25' between said source 23 and the various well heads will permit the controlled and selective introduction of flows of steam through the various wells in a manner to best achieve the objectives of the invention.

Structurally, the various wells, both horizontal and vertical, are formed into a substrate after a determination has been made regarding the character and composition of the productive layer. Vertical wells as in the instance of most productive wells 17 and 18, are initially spudded downwardly in a vertical direction. The well bore is continued downwardly to penetrate the overburden layer 19 and tar sand layer 16.

When the latter is found beneath a substantial thickness of overburden, the well bore can be provided with the necessary casings which progressively decrease in diameter until the desired casing size is ultimately inserted into the productive layer 16. This latter casing as herein noted can be pre-perforated along its length before being inserted and fixed into place. However, the casing can also be inserted as to reside within the productive layer, and thereafter perforated in a manner to permit the desired discharge of stimulating fluid into the productive subsection 16.

Depending on the composition of the substrate wherein the hydrocarbons are held, casing perforations can take the form of a series of narrow slots rather than through holes through which the produced hydrocarbons will flow. These slots can be designed to readily allow the flow of hydrocarbon emulsion and yet minimize the flow of sand which is normally carried from the substrate by the flowing emulsion.

Broadly speaking, the preferred method for producing according to the invention resides in the segregation of a discrete productive subsection 16 of a productive subterranean layer. The subsection to be initially produced is in effect at least partially bounded by or marginated by the above noted three wells 17, 18 and 21 disposed respectively at either lateral ends of the subsection and along the bottom thereof.

To commence and sustain a flow of hydrocarbon fluid or emulsion from the subsection, a pressurized flow of steam is introduced to said subsection from multiple directions. The latter are preferably from the underside by way of well 21, as well as laterally from injection well 17. This injection of stimulation by steam injection will cause the limited subsection to be preheated in anticipation of the subsequent production step.

Thereafter, the lateral flow of stimulating steam from the injection well 17 will cause a thermal front to be established. Under the influence of the pressure of both steam flows at wells 17 and 21, the thermal front will be caused to advance laterally through the substrate and toward producing well 18. Thereafter, the heated hydrocarbon product normally in the form of viscous oil, or bitumen emulsion which has formed from steam condensate, can be received in the well 18 and product.

To best achieve the preheating step of the productive subsection, a flow of pressurized steam is initially introduced by way of well head 26 through horizontal well 21 to the lower side of the productive layer 16. As seen

in FIG. 2, this initial introduction of steam will take place along the entire horizontal length of well 21. However, due to the gradual pressure drop-off in the steam as the well progresses toward its remote end, the injected steam will define a temperature profile 27 approximately as illustrated in FIG. 2.

During this initial preheating period, the temperature of the substrate adjacent to the area about the horizontal well 21 will be progressively raised. The viscous hydrocarbon or the bitumen will thereby become less viscous, or in the case of the bitumen will become flowable. The bitumen emulsion, will gravitate downwardly and into horizontal well 21 thus establishing voids through the substrate immediately adjacent to well 21.

After the initial preheating of the productive substrate 16 has been achieved, introduction of a secondary flow of steam by way of injection well 17 can proceed. Such injection by way of flows 28, will result as shown in FIG. 3, of a laterally moving steam front which combines with the upwardly moving steam from the horizontal well 21. The two combined fronts define an aggregate thermal front as defined by the line 29.

As herein mentioned, cavitation of, and forming of voids in the substrate during the preheat period will take place. Thus, steam from the injection well 17 will penetrate more rapidly through the substrate and toward the remote end of horizontal well 21. The advancing thermal front as defined by a relatively constant temperature, will assume a curvature approximately as shown and designated at 29, of about 400° F. In a similar manner, and as shown in FIG. 3, the areas remote from the two steam injection sources 17 and 21 will define spaced apart temperature curvatures of 300° and 200° F.

The character of the steam introduced into the substrate to achieve the stimulating action will be adjusted in accordance with the conditions prevailing within the substrate. For a relatively deep productive layer it is understood that the necessary steam pressure for penetrating the earthen productive layer will be substantially greater than when the layer is near to the earth's surface.

The temperature of injected stimulating steam for the herein noted method can vary with a range of about 212° F. to 750° F.

In either instance, steam which is introduced to both vertical and horizontal wells, and which is subsequently combined within the substrate to form the aggregate thermal front, need not be of equal quality nor injected under equal conditions. The temperature and pressure of the multi-directional flows, that is from horizontal and vertical, should however be relatively compatible. This is desirable in order that an orderly flow of the combined steam fronts will tend to move the aggregate thermal front laterally through the productive layer and toward well 18.

The affect of incoming steam from both the horizontal and vertical wells on the substrate is monitored during the entire stimulating step. This can be achieved in one way through use of thermocouples and similar pressure sensitive instruments which are embedded into the substrate in a desired pattern to be in the path of the advancing thermal front.

By monitoring the changing conditions within the subsection 16, the rate of flow as well as the temperature and pressure of injected steam whether vertically or horizontally injected, can likewise be regulated to achieve the desired laterally advancing thermal front.

One or both of the wells 17 and 21 being utilized for steam stimulation can be provided with packers or similar equipment which functions to limit the length of well along which the steam is injected. Thus, one or more blocking members, such as well packers can be inserted into the respective wells and positioned. Said members can be subsequently adjusted during the steam injection period to assure that the desired outflow of steam from both horizontal and vertical sources is properly regulated.

Over an extended period of operating time, and referring to FIGS. 4 and 5, the thermal fronts within productive layer 16 as characterized in FIG. 4 by the lines 31 and 32 respectively designating 400° and 300° F. temperatures, will advance toward the producing well 18. This pressurized thermal front will progressively drive the less viscous hydrocarbon toward said producing well so that the hydrocarbon emulsion can be produced. Concurrently, and as shown in FIG. 5, as the productive layer becomes more thoroughly heated, and produced, the degree of oil saturation thereof, shown as curves 33 and 34, will be decreased as a function of the temperature.

During both the preheating and the subsequent producing period and as noted herein, a considerable amount of the viscous crude or the bitumen will be initially put into flowable condition. It will gravitate downwardly toward horizontal well 21. Thus, for a limited period the latter can function as both an injection and as a production well by operating on the huff and puff sequence. This will of course be mandated by the amount of hydrocarbon emulsion which does flow downward to accumulate in lower well 21.

By regulating the cycling of said well through sequential heating and productive steps, the condition of the substrate thereabove can be controllably maintained to sustain the lateral movement of the thermal front toward the producing vertical well 18.

After a period of the above noted thermal treatment of the productive substrate 16, breakthrough at the producing well 18 will result. Further, after a period during which the hydrocarbon emulsion is produced, a point will be reached when a substantial amount of the output from producing well 18 is found to be the injected stimulating steam.

This circumstance will indicate a substantial depletion of hydrocarbon from the productive layer 16 and the free passage of stimulating steam through the thereby created voids. At this point, the process can be considered as being completed or non-productive.

Referring to FIG. 6, to apply the presently disclosed method to a relatively large field or productive layer, a series or pattern of well combinations can be inserted in the field. Thus, the arrangement of wells to form the combined vertical and horizontally defined subsection of the productive layer, can be as shown in FIG. 6.

Here, the respective wells are arranged in a generally square-like pattern, combining both the horizontal and vertical wells.

As seen in FIG. 7, the respective horizontal wells 36 and 37 can be commenced or spudded at a common point at approximately the center of the field. Thereafter, the various vertical wells 38, 39 and 40 are judiciously placed about said center to best effectuate the injection of steam into a particular discrete subsection of the productive layer 41.

The outer or remote edges of the square pattern of FIG. 6 are provided with a series of vertical producing

wells designated as V1 to V8 inclusive. These, as shown, are formed to terminate adjacent to the remote end of the various horizontal wells H1 to H8, respectively.

The pattern is completed by a series of vertical injection wells V9 to V12 which are disposed closely adjacent to the center of the pattern.

It should be understood that there is no particular sequence in forming the various horizontal and vertical wells into a substrate to establish the above noted pattern. It is understandable, however, that at such time as the pattern is formed, the selective introduction of steam and the production of vertical subsections of the producing area should be regulated such that the volume of steam is most effectively utilized.

Thus, a progression of hydrocarbon production can be made by sequentially producing from the various wells at the outer periphery of the pattern. Concurrently, the various horizontal wells, as well as the vertical injection wells, are selectively stimulated in such manner that each vertical segment of productive layer will be heated only in its limited subsections as herein noted.

The invention has been described as embodying basically two spaced apart vertical wells, together with a horizontal well. Further, the horizontal well extends adjacent to or in the vicinity of the lower ends of the respective vertical wells.

Although the foregoing illustrates one preferred embodiment of the invention, the novel method can be practiced particularly by varying the character of the horizontal well. For example, the latter need not extend for the full distance between the two vertical wells. The aggregate front can be established to effectively sweep the substrate section, if the horizontal well extends for only a part of the distance between said vertical wells.

Although modifications and variations of the invention may be made without departing from the spirit and scope thereof, only such limitations should be imposed as are indicated in the appended claims.

We claim:

1. Method for producing viscous hydrocarbon from a productive substrate layer in which the hydrocarbon is releasably held, which method includes the steps of:
 segregating a discrete vertical subsection of said substrate layer which is marginated between a pair of laterally spaced, substantially vertically oriented wells, and at least one other well, a portion of the latter being disposed substantially horizontal, and positioned adjacent to the bottom of the laterally spaced vertical wells,

said respective vertical walls and at least one other well, being perforated along a portion of the lengths thereof which contacts the productive substrate layer,

preheating said discrete vertical subsection, introducing multi-directional flows of a pressurized heating medium concurrently from one of said vertical wells and the horizontal well respectively, into said vertical subsection to form thermal fronts in the productive layer, which fronts combine to establish an aggregate thermal front which is urged toward the other of said laterally spaced vertically oriented wells,

producing hydrocarbon from said other vertically oriented well,

and the production of hydrocarbon from said vertical subsection by way of said at least one other well is achieved prior to the introduction of said multi-directional flows of heating medium thereto, and subsequent to said vertical subsection becoming preheated.

2. Method for producing viscous hydrocarbon from a productive substrate layer in which the hydrocarbon is releasably held, which method includes the steps of:

segregating a discrete vertical subsection of said substrate layer which is marginated between a pair of laterally spaced, substantially vertically oriented wells, and at least one other well, a portion of the latter being disposed substantially horizontal, and positioned adjacent to the bottom of the laterally spaced vertical wells,

said respective vertical walls and at least one other well, being perforated along a portion of the lengths thereof which contacts the productive substrate layer,

preheating said discrete vertical subsection, introducing multi-directional flows of a pressurized heating medium concurrently from one of said vertical wells and the horizontal well respectively, into said vertical subsection to form thermal fronts in the productive layer, which fronts combine to establish an aggregate thermal front which is urged toward the other of said laterally spaced vertically oriented wells,

producing hydrocarbon from said other vertically oriented well,

sequentially preheating and producing hydrocarbon from the vertical subsection by way of said at least one other well, prior to the introduction of said multi-directional flows of heating medium thereto.

* * * * *

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(18) (CA) **CANADIAN PATENT** (12)

(54) Cyclic Solvent Flooding to Recover Viscous Oils

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U.S.A.

(73) Granted to Mobil Oil Corporation
U.S.A.

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(22) FILED 851111

No. OF CLAIMS 9

Canada

REPRODUCED FROM THE PATENT OFFICE OF CANADA

CYCLIC SOLVENT FLOODING TO RECOVER VISCOUS OILS

This invention is directed to a method of recovering oil from viscous oil-containing subsurface formations. More particularly, this invention is directed to a cyclic hydrocarbon solvent recovery method for recovering oil from subsurface formations that are penetrated by at least one injection well and one production well which extend downwardly from the surface of the earth into the bottom of the oil-containing formation and then extend horizontally through the formation.

In U.S. Patent No. 4,373,585 of John L. Fitch et al., issued February 15, 1983, there is disclosed a method of recovering viscous oil from a viscous oil-containing formation wherein a selected solvent is injected into a fluid communication path in the lower portion of the formation intermediate at least an injection well and a production well. A hydrocarbon solvent having a density less than oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions is injected into the communication path and fluids including oil are recovered from the production well until the fluid recovered contains an unfavorable ratio of oil to solvent. The production well is shut-in and an additional quantity of the hydrocarbon solvent is injected into the fluid communication path, preferably until a total amount of between 0.05 to 0.30 pore volume has been injected. The injection well is then shut-in along with the production well to permit the formation to undergo a soak period for a variable time, preferably for a time of between 2 to 20 days per vertical thickness in feet of oil-containing formation. A driving fluid such as water is then injected into the formation via the injection well and the oil is produced until there is an unfavorable ratio of oil to driving fluid. During the fluid drive recovery phase, the injection well and production well may be completed to be in fluid communication with the entire portion of the formation to obtain a more uniform displacement of the upgraded formation oil by the driving fluid.

*

In U.S. Patent No. 4,293,035 of John L. Fitch, which issued October 6, 1981, there is disclosed a method of recovering viscous oil from a viscous oil-bearing subsurface formation wherein a solvent is injected into a high mobility channel formed in the bottom of the formation intermediate an injection well and a production well. The solvent is injected until the ratio of produced oil to solvent becomes unfavorable and thereafter the injection of solvent is terminated and gas is injected into the high mobility channel to produce solvent and oil from the formation.

In U.S. Patent 3,838,738 there is described a method for recovering viscous petroleum from petroleum-containing formations by first establishing a fluid communication path low in the formation. A heated fluid is then injected into the fluid communication path followed by injecting a volatile solvent such as carbon disulfide, benzene or toluene into the preheated flow path and continuing injecting the heated fluid and recovering fluids including petroleum from the production well.

In U.S. Patent 3,900,917 there is disclosed a method for recovering crude oil from an oil-bearing formation having a water-saturated zone underlying the oil-saturated zone. A mixture of an aqueous fluid which has a density greater than the density of the crude oil and a solvent having a density less than the density of the crude oil are injected into the water-saturated zone and oil is produced from the formation.

U.S. Patent 4,026,358 discloses a method for recovering heavy oil from a subterranean hydrocarbon-bearing formation traversed by at least one injection well and one production well wherein a slug of hydrocarbon solvent in amounts of 0.1 to about 20 percent of the formation pore volume and having a gas dissolved therein is injected into the formation via the injection well. Thereafter, a thermal drive is created in the formation by in-situ combustion or by injecting steam. The wells are then shut-in for a predetermined time to permit the formation to undergo a soak period, after which production is continued. Optionally, after the production period, the formation may be water flooded to recover additional oil from the formation.

This invention is directed to a method of recovering viscous oil from a viscous oil-containing formation that has no significant vertical permeability barrier in the portion of the formation being produced involving at least one injection well and at least one spaced-apart production well that penetrate the formation and then extend horizontally through the bottom of the formation for cyclic injection of solvent into the formation and recovery of oil from the formation. The injection well and production well are drilled into the formation extending downwardly from the earth's surface to the bottom of the oil-containing formation and then a substantial distance through the formation in a generally horizontal direction. That portion of the injection well and production well that extends horizontally through the bottom of the formation is perforated or otherwise equipped to provide fluid communication between both wells and the formation. The production well is spaced-apart from the injection well but the horizontal portion of the production well is at the same level as, and parallel to, the horizontal portion of the injection well. A hydrocarbon solvent having a viscosity not greater than 1/100 the viscosity of the oil contained in the formation and a specific gravity less than the oil contained in the formation under formation conditions, is injected into the bottom of the formation via the injection well and fluids including oil are recovered from the production well until the produced fluid contains an unfavorable amount of solvent, preferably at least 90 percent. When this occurs, injection of solvent is terminated and both the injection well and production well are shut-in for a predetermined period of time to allow the formation to undergo a soak period. The soak period is preferably for 2 to 30 days per foot of vertical thickness of the oil-containing formation. During this soak period, the light hydrocarbon solvent will tend to rise and the heavy oil will move downward in a gravity-driven convection process forming a pattern of fingers. This fingering causes a more effective contact between the oil and solvent thereby allowing the two to mix more effectively, thus providing a greater volume of oil that is reduced in viscosity. After the soak period, the hydrocarbon

solvent is injected into the bottom of the formation via the production well and fluids including oil and solvent are recovered from the formation via the injection well until the fluid being produced contains an unfavorable amount of solvent, preferably at least 90 percent. In another embodiment of the invention, following completion of the soak period, the fluid produced from the injection well which is primarily solvent is re-injected or recycled into the formation via the production well in place of pure solvent until the amount of solvent in the produced fluid is less than 90%. Thereafter, recycle of the produced fluid is terminated and pure hydrocarbon solvent is injected into the formation via the production well and production of fluids from the injection well continued until the fluid being produced contains an unfavorable amount of solvent, preferably at least 90 percent. After injection of solvent into the production well is terminated, both wells are shut-in to allow the formation to undergo a second soak period for a predetermined period of time, preferably for 2 to 20 days per foot of formation thickness. Thereafter, a driving fluid such as water is injected into the injection well to displace the mixture of oil and solvent toward the production well for recovery. Production is continued until the fluid including oil recovered from the production well contains an unfavorable ratio of oil to driving fluid.

The term "viscous oil" is used herein to identify oil having relatively high viscosity and includes those oils referred to as tars. Such viscous oils are also referred to as heavy oils. In general, the term viscous oil is used to include those heavy oils and tars such as are commonly found in formations referred to as heavy oil or tar sands that have viscosities that are great enough to severely restrict the production of the oils from the formations in which they are found. The API gravity of such viscous oils is normally 20° API or less.

In the accompanying drawings,

Figure 1 is a diagrammatic plan view of an area which overlies an oil-containing formation, and indicates by dotted lines an injection well and a production well which extend downwardly from the surface to the bottom of the oil-containing formation.

Figure 2 is a sectional view taken along the line 2-2 showing the manner in which the injection well and production well penetrate the formation, and

Figure 3 is an isometric view of a rectangular block of the earth showing the position of the injection well and the production well within the formation.

Referring to the drawings, a field 10 overlying an oil-containing formation is provided with an injection well 12 and a production well 14. As shown in Figures 2 and 3, the injection well 12 and the production well 14 extend downwardly from the earth's surface 16, through an overburden 18, into the oil-containing formation 20 and then extend a substantial distance horizontally through the bottom of the formation. The production well 14 is spaced apart from the injection well 12 and the horizontal portion of the production well is at the same level and parallel to the horizontal portion of the injection well. The horizontally extending portion of the injection well 12 and the production well 14 have perforations 22 providing fluid communication between that portion of each well and the lower portion of the formation 20. Although only one injection well and one production well are shown for purposes of illustration, it is to be understood that a plurality of alternating spaced apart injection wells and production wells may be used with the number depending upon the characteristics of the oil-containing formation. The wells may be formed by conventional directional drilling means with the horizontally extending portion of each well in the bottom of the formation being within plus or minus 20° or more preferably within minus 20° of a horizontal plane.

A hydrocarbon solvent having a specific gravity less than the specific gravity of the oil contained in the formation and having a viscosity not greater than 1/100 of the viscosity of the oil contained in the formation under formation conditions is injected via the injection well 12 and fluid including oil is recovered from the formation via production well 14. Solvent injection is continued until

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the fluid being produced from the formation by means of production well 14 comprises an unfavorable amount of solvent, preferably at least 90 percent.

Thereafter, injection of the solvent is discontinued and both the injection well 12 and production well 14 are shut-in to allow the formation 20 to undergo a soak period for a variable time, preferably for a period of time between 2 to 20 days per foot of the vertical thickness of the oil-containing formation. It will be recognized by those skilled in the art of oil recovery that during this shut-in or soak period minor amounts of fluid may be injected or produced, such as for the purpose of testing, without significant detrimental effects on the process. During the soak period, the liquid hydrocarbon solvent being lighter than the oil contained in the viscous oil-containing formation, that is, having a specific gravity less than the specific gravity of the oil contained in the formation and having a viscosity not greater than 1/100 of the viscosity of the oil contained in the formation under formation conditions, will tend to flow by gravity-driven convection upward into the oil-containing formation and the heavy oil will flow by gravity-driven convection downward forming a pattern of fingers. This fingering is important in that the distribution, size and extension of these fingers will provide intimate contact between the solvent and the heavy oil allowing the two to mix more effectively, thus forming a greater volume of oil that is reduced in viscosity and which can be produced more readily.

Once the soak period has been completed, hydrocarbon solvent is injected into the formation via the production well 14 and fluid including oil is recovered from the formation via the injection well 12. Solvent injection is continued until the fluid being recovered from the formation by means of the injection well 12 comprises an unfavorable amount of solvent, preferably at least 90 percent. Thereafter, production of fluids from the formation by means of injection well 12 is terminated and both the injection well 12 and production well 14 are shut-in for a predetermined period of time to

allow the formation to undergo a second soak period. The second soak period is preferably 2 to 20 days per foot of formation thickness being treated.

When the injection well is placed on production at the end of the first soak period, the produced fluid will consist primarily of solvent. Therefore, in another embodiment of our process to permit maximum solvent usage together with minimizing the quantity required, the fluid recovered from the injection well after the first soak period is re-injected or recycled into the formation via the production well 14 in place of pure solvent until the amount of solvent in the fluid produced from the injection well is less than 90%. Once the solvent content of the produced fluid drops to less than 5%, recycle of this fluid is terminated and pure solvent is injected into the production well. Injection of the pure solvent is then continued until the amount of solvent in the fluid being produced from the formation by means of injection well 12 contains an unfavorable amount of solvent, preferably at least 90 percent.

The above sequence of solvent injection, production and soak period followed by repeating these steps after converting the production well to an injection well and the injection well to a production well may be repeated for as many cycles as is desired.

Thereafter, a driving fluid is injected into the formation 20 via the injection well 12 to displace the oil of reduced viscosity from the formation into the production well 14 and production is continued until the recovered fluid contains an unfavorable amount of driving fluid, preferably at least 90 percent. The driving fluid may be gaseous or liquid and is preferably an aqueous fluid. Suitable gaseous driving fluids include light aliphatic hydrocarbons having from one to four carbon atoms, carbon dioxide or nitrogen. Suitable aqueous fluids include water, brine or thickened water.

The hydrocarbon solvents used in our process must have a specific gravity less than that of the oil and less than that of the brine injected or naturally present in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the

formation under formation conditions. It is also highly desirable that the hydrocarbon solvent remain liquid under the temperature and pressure conditions that exist in the subsurface viscous oil-containing formation and not cause solids such as asphaltenes to precipitate from the oil in amounts sufficient to seriously plug the pores of the formation. The preferred hydrocarbon solvent is a light crude oil. Other examples of suitable hydrocarbon solvents include light oil condensates having an API gravity greater than 30 API degrees and partially refined tar which is generally known as syncrude. It may be desirable to include in the hydrocarbon solvent up to about 10 percent of aromatic material such as aromatic refinery stock to make the solvent compatible with the oil contained in the formations and to prevent the deposition of solid or gelatinous materials such as asphaltenes therefrom.

The viscous oil-containing subsurface formation to be treated by the present hydrocarbon solvent recovery method must be one that has no significant vertical permeability barriers in that portion of the formation to be treated. This allows the solvent that is injected into the bottom of the formation between the injection well and production well to flow upward into the formation by convection forces thus solubilizing the oil and forming a solvent-oil mixture of reduced viscosity that can be more readily produced.

In a further embodiment, the injection well and the production well may extend downwardly from the earth's surface into the bottom of the oil-containing formation with the lower portion of each well extending through the formation at a downward angle not greater than 20° relative to a horizontal plane and the lower portion of each well in fluid communication with the formation. The production well is spaced apart from the injection well and the lower portion is at the same level and parallel to the lower portion of the injection well.

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CLAIMS:

1. A method of recovering viscous oil from a subterranean viscous oil-containing formation having no significant vertical permeability barrier therein comprising the steps of:

- (a) providing at least one injection well extending downwardly from the earth's surface to the bottom of said oil-containing formation wherein the lower portion of the well extends through the formation at a angle not greater than 20° relative to a horizontal plane;
- (b) providing at least one production well extending downwardly from the earth's surface to the bottom of said oil-containing formation wherein the lower portion of the well extends through the formation at a angle not greater than 20° relative to a horizontal plane, said production well being spaced from said injection well but the lower portion of said production well being generally at the same level as, and being generally parallel to, the lower portion of said injection well, and said injection well and said production well being in fluid communication with the lower portion of said formation;
- (c) injecting a hydrocarbon solvent into the formation via said injection well, said solvent having a specific gravity less than the specific gravity of the oil contained in the formation and a viscosity not greater than $1/100$ the viscosity of the oil contained in the formation under formation conditions and recovering fluids including oil and solvent from the formation via the production well until the fluid being recovered comprises an unfavorable amount of solvent;

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- (d) shutting-in said wells to permit said formation to undergo a soak period for a predetermined period of time;
- (e) thereafter injecting a hydrocarbon solvent into the formation via said production well, said solvent having a specific gravity less than the specific gravity of the oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions and recovering fluids including oil and solvent from the formation via the injection well until the fluid being recovered comprises an unfavorable amount of solvent;
- (f) shutting-in said wells to permit said formation to undergo a soak period for a predetermined period of time; and
- (g) thereafter injecting a driving fluid into the formation via said injection well and recovering fluids including oil from said formation via said production well until the fluid being recovered from the production well comprises an unfavorable amount of driving fluid.

2. The method of Claim 1 wherein steps (c) through (f) are repeated for a plurality of cycles.

3. The method of Claim 1 wherein the soak period during steps (d) and (f) is for a period of time between 2 and 20 days per foot of vertical thickness of the oil-containing formation.

4. The method of Claim 1 comprising the additional step following step (d) of producing fluid including oil and solvent from the formation via said injection well and re-injecting said fluid into the formation via said production well until the amount of solvent in said fluid is less than 90 percent.

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5. The method of Claim 1 wherein the driving fluid is a gaseous material selected from the group consisting of carbon dioxide, nitrogen or aliphatic hydrocarbons having one to four carbon atoms.

6. The method of Claim 1 wherein the driving fluid is water.

7. The method of Claim 1 wherein said hydrocarbon solvent is selected from the group consisting of a light crude oil having an API gravity greater than 30 API degrees and a light crude oil product generally known as syncrude.

8. The method of Claim 1 wherein the production of fluids from the formation according to steps (c) and (e) is continued until the recovered fluids contain at least 90 percent solvent.

9. The method of Claim 1 wherein the production of fluids from the formation according to step (p) is continued until the recovered fluids contain at least 90 percent driving fluid.

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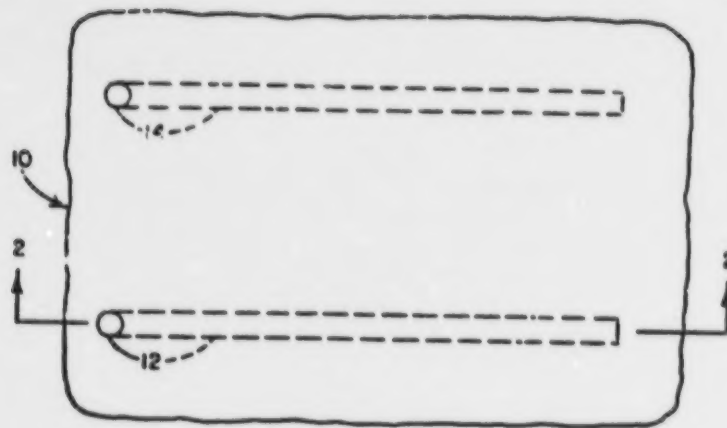


FIG. 1

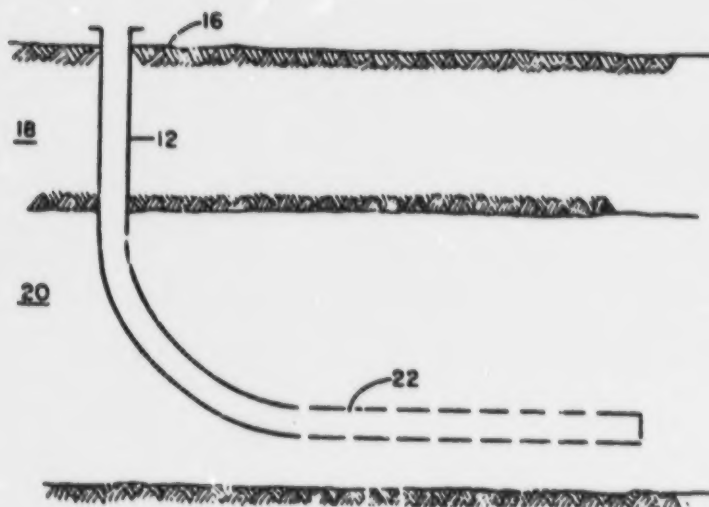
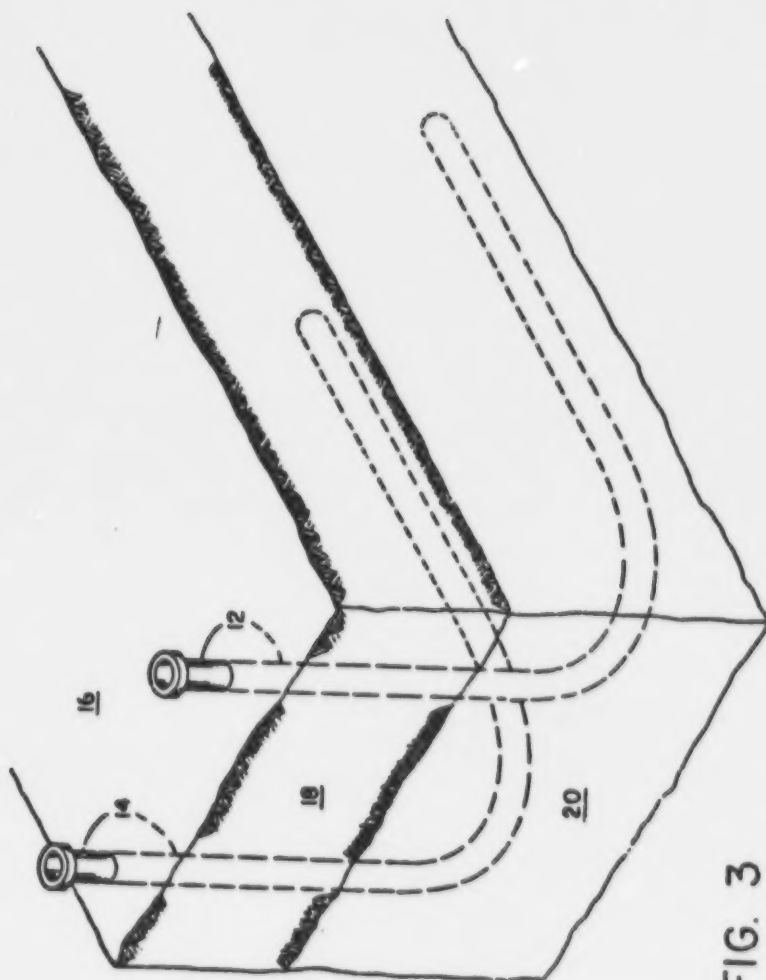


FIG. 2

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RESEARCH AUTHORITY
Library and Information Services

United States Patent [19]

Huang et al.

[11] Patent Number: **4,558,742**[45] Date of Patent: **Dec. 17, 1985****[54] METHOD AND APPARATUS FOR GRAVEL
PACKING HORIZONTAL WELLS**[75] Inventors: Wann-Sheng Huang; Alfred Brown,
both of Houston, Tex.[73] Assignee: **Texaco Inc.**, White Plains, N.Y.[21] Appl. No.: **630,506**[22] Filed: **Jul. 13, 1984**[51] Int. Cl.⁴ **E21B 43/04**[52] U.S. Cl. **166/278; 166/51**[58] Field of Search **166/51, 50, 278****[56] References Cited****U.S. PATENT DOCUMENTS**

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Primary Examiner—Stephen J. Novosad*Assistant Examiner*—M. Goodwin*Attorney, Agent, or Firm*—Robert A. Kulason; James J. O'Loughlin; Robert B. Burns**[57] ABSTRACT**

A well completion and the method therefor for a wellbore which extends generally horizontally of a subterranean layer comprised primarily of unconsolidated sand particles which hold a viscous hydrocarbon. The completion includes an elongated perforated liner which is positioned in the wellbore. The liner is substantially surrounded by a gravel pack which functions to limit the amount of sand particles which are carried from the subterranean layer into the liner in response to the introduction of a flow of a hot stimulating fluid into the substrate.

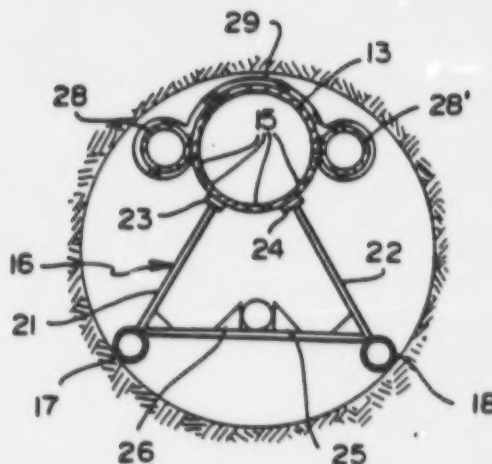
5 Claims, 6 Drawing Figures

FIG. 1

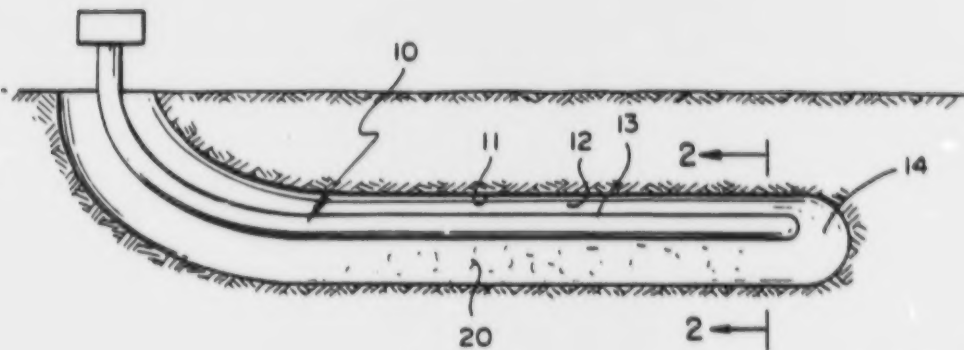


FIG. 2

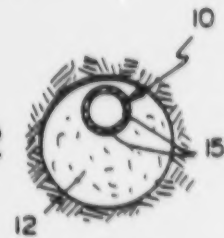


FIG. 3

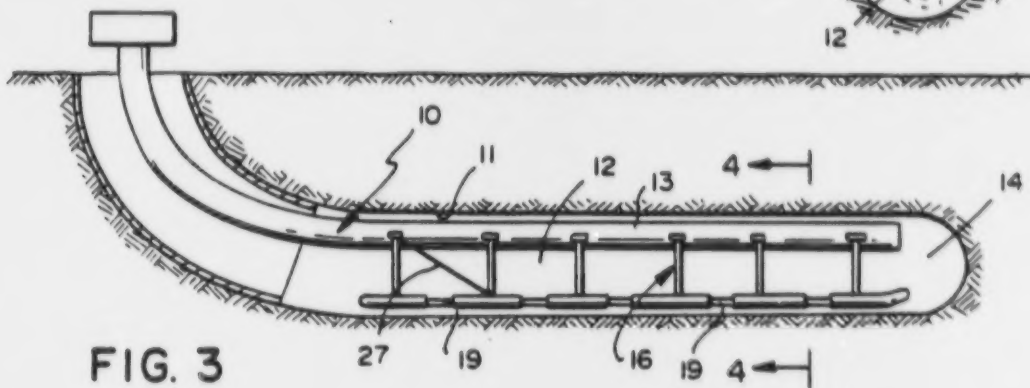


FIG. 4

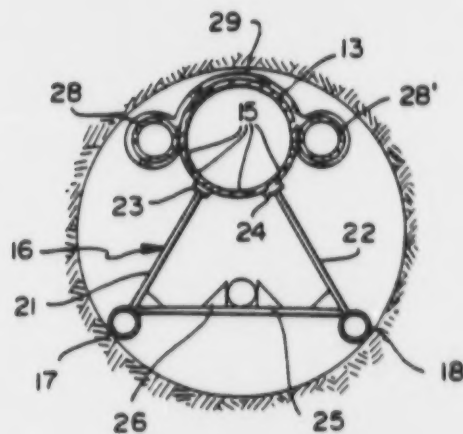


FIG. 5

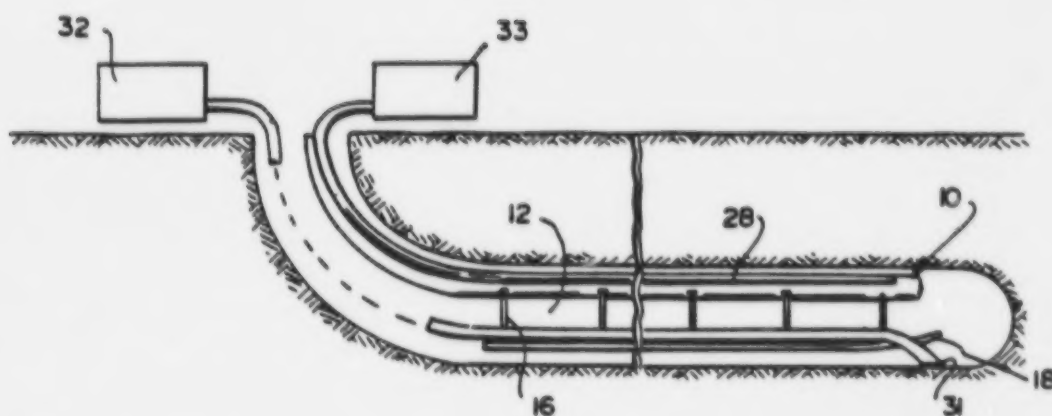
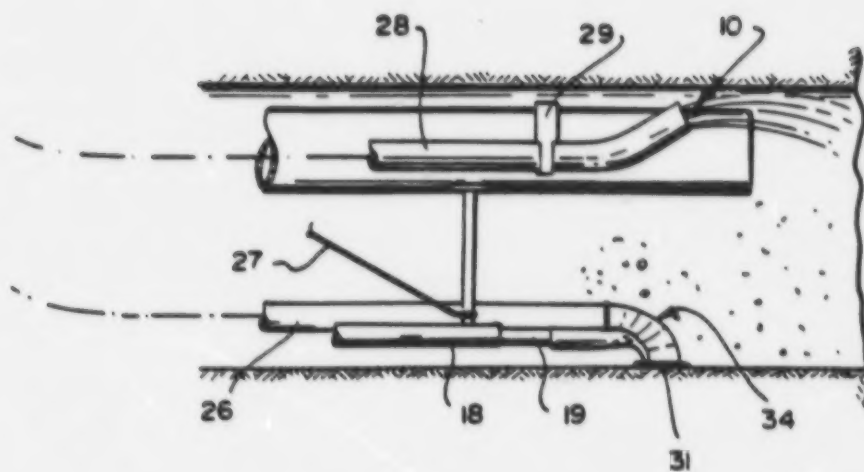


FIG. 6



METHOD AND APPARATUS FOR GRAVEL PACKING HORIZONTAL WELLS

BACKGROUND OF THE INVENTION

In the production of hydrocarbons, such as crude oil and bitumen from a subterranean reservoir, the characteristic of the formation has a substantial effect on the efficiency of production. It is expected that in the course of most production operations, the flowing hydrocarbon will carry with it an amount of the substrate from which it is being lifted. This effect is particularly noticeable in the instance of sandy formations which are subjected to thermal stimulation.

In the instance of a substrate comprised largely of unconsolidated sand particles, the flowing hydrocarbon will tend to carry excessive amounts of sand with it. Sand thus entering the well casing or liner, forms a substantial part of the flow and has detrimental effects on the overall operation, as well as on the equipment. For example, the size of the sand particles could be such that there is a propensity for it to block or at least partially plug holes and passages through which the flow passes. Further, the abrasive nature of the sand results in the wearing away or damage to parts which make up the well completion.

Operationally, the combined sand and hydrocarbon flow have to be treated and separated after being produced. The equipment needed for such separation generally constitutes a major and costly part of the production facility in which sand is a prevalent factor.

It can be appreciated that in the instance of bitumen production, and the production of viscous crude oil from a sandy environment, the problem of sand control will pose a major consideration. In the specific instance of bitumen, the normal thermal stimulation of a substrate through the use of hot fluids such as steam, will tend to promote the flow of sand. As the bitumen or viscous crude is released, it will carry along with it varying sized sand particles in its flow to the production string.

It has been found that where the hydrocarbon holding reservoir constitutes a relatively thin layer, there are advantages in the use of horizontal wells. The latter extend coextensively with the productive layer and can be more economical than a series of vertical wells, which pass through the layer at spaced apart points.

In the instance of a horizontal well, similarly to a vertical well, a pressurized hot medium is used to stimulate the substrate adjacent to the well. Thereafter the viscous hydrocarbon is caused to flow and gravitate toward the single well, and be produced as a hot, flowing stream.

In the instance of horizontal wells which are formed into tar sands, the problem of excessive sand production is particularly acute. As above noted, the hot bitumen is stimulated and caused to assume a fluid state, thereby carrying with it substantial quantities of sand which will enter the wall perforations in the horizontally positioned liner. These sand particles will tend to narrow such passages to a minimum opening, or completely obviate flow therethrough.

Efforts have been made through the use of replaceable screens, to minimize this flow of sand into a horizontal producing well. However, the very nature of the well, because it extends horizontally rather than vertically, introduces problems not heretofore contemplated with respect to the in-situ formation of a suitable gravel

pack. Since a gravel pack is among the most prevalent ways of minimizing sand production in vertical wells, such packs are considered to be of comparable efficiency if they can be adapted to be utilized in conjunction with a horizontal well.

The state of the art relative to in-situ gravel packing of hydrocarbon producing wells covers a broad spectrum of apparatus and methods. Essentially, however, the art is concerned primarily with packing of vertical and/or deviated wells, with open or closed casing, in which the gravel injection can be achieved by a gravity flow.

Examples of this type of gravel packs are disclosed in U.S. Pat. Nos. 4,066,127 and 4,124,074. In the shown patents, the gravel is introduced through the well and carried into a preformed vertical well cavity whereby to constitute the required sand barrier. This introduction of the gravel is achieved either by feeding the gravel alone, or in the form of a slurry.

In U.S. Pat. No. 2,434,239, the patentee extends the gravel pack concept into a portion of a deviated or sloping well, and even into a portion of a horizontal well. However the gravel as shown, particularly in the patentee's FIG. 3, is introduced to fill the entire borehole. This is achieved by progressively withdrawing the gravel carrying conduit as the borehole fills. The patentee's disclosure lacks the means for providing a gravel pack which surrounds the well liner and forms the necessary peripheral barrier to sand.

U.S. Pat. No. 3,261,401 is concerned at least in part with a gravel pack within a horizontal well. The pack in this instance, and as shown in FIGS. 4 and 5, is an integral part of the well liner, and is not installed in-situ.

Toward overcoming the foregoing problems, and for providing an in-situ gravel pack, the disclosed well completion is one that is commenced by first forming an elongated bore. The latter extends substantially horizontally whereby to lie longitudinally through a productive layer.

A perforated well liner or casing having a diameter substantially less than the diameter of the wellbore, is supportably positioned in the bore in a manner to define an annular passage. Said passage between the liner wall and the adjacent wall of the bore, is then furnished with a gravel pack. The pack is comprised of an unconsolidated mass of gravel sizes and grades which have been predetermined for the particular formation composition, to best form a barrier to migrating sand particles which would otherwise enter the liner.

The gravel pack annular cavity or longitudinal passage is formed by positioning the liner initially in the wellbore prior to introducing a gravel carrying slurry to said longitudinal passage. Thereafter, the pack is completed by introduction of the gravel slurry about the liner sides as a slurry carrying conduit is progressively withdrawn from the well.

It is therefore an object of the invention to provide a gravel pack and method for use thereof in a substrate comprising a sandy composition and into which at least one horizontal producing well has been formed.

A further object is to provide a method for forming a gravel pack in situ about a horizontally extending well.

A still further object is to provide a gravel pack and method for applying the same about a well liner that is positioned in a horizontally extending wellbore.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional elevation view of a horizontal, gravel packed well completion.

FIG. 2 is a sectional view taken along line 2—2 in FIG. 1.

FIG. 3 is similar to FIG. 1, prior to the gravel being placed.

FIG. 4 is a sectional view taken along line 4—4 of FIG. 3.

FIG. 5 is a vertical cross sectional view of an alternate embodiment of the invention.

FIG. 6 is a segmentary view in cross section of an alternate embodiment of a horizontal well.

Referring to the Figures, a well completion 10 of the type contemplated is shown positioned in a generally horizontal disposition within a wellbore 11 in a substrate 20 comprised of a sandy composition.

Normally a producing well of this type is formed by commencing the wellbore 11 at the surface, either in a vertical or a downward slanted direction. Thereafter, at the productive layer, the well is diverted to extend in a substantially horizontal direction.

Preferably, wells of this configuration are employed where the productive substrate comprises a relatively thin layer. They can, however, also be used in producing thick layers. Thus, the wellbore 11 can extend for any desired distance along the layer to best provide the stimulating medium for heating the viscous hydrocarbon, and for carrying away the resulting hydrocarbon emulsion or mixture.

Horizontal wells of the type shown can be utilized by themselves as a production means. Alternatively, a series of horizontally extending wells cooperatively arranged, can be employed to supplement the function of each other through sequential thermal stimulation and production steps.

In the present arrangement, and to illustrate the invention, the novel gravel pack 12 and its method of application will be described with respect to a single horizontally extending well which is positioned in a tar sand environment for producing a bitumen emulsion.

In a normal tar sand layer, the formation is comprised of different sand particle sizes with the bitumen retained therebetween. The bitumen, however, is too thick or viscous to flow without thermal stimulation such as by steam or hot water injection into the formation.

Horizontal wellbore 11 is provided with a liner or casing 13 which is positioned within bore 11. The liner carries the dual purpose of introducing a heating medium to the surrounding substrate, and producing the resulting bitumen emulsion. Liner 13 is therefore provided with openings such as perforations or slots 15 formed in the wall thereof. The latter are of a size capable of permitting an outflow of a heating medium such as steam, and the resulting inflow of the hot bitumen emulsion.

As herein mentioned, inflowing bitumen usually results in the presence of substantial amounts of varied size sand particles. The latter, depending on their size, will accumulate and clog or impair flow through the relatively constricted liner wall openings 15.

Were these openings to be made larger to accommodate the flow of sand without promoting a blocking action, the excessive sand build-up would soon function to impede operation of downstream equipment such as pumps, separators, and the like.

Elongated steel liner 13 is prepositioned within wellbore 11 to best achieve the desired filtering action whereby to minimize sand flow through liner perforation 15. Thus, and as shown in FIG. 1, in one embodiment liner 13 is positioned adjacent to or contiguous with the upper side of the wellbore 11. The subsequently installed gravel pack 12 will thereby fill the annulus defined by the adjacent walls of said liner and bore.

In the illustrated configuration, to achieve maximum filtering action liner 13 can be provided with narrow slots or openings 15 for only a portion of the wall periphery. These would be found adjacent to the lower side of the liner. Inflowing bitumen emulsion will thereby be caused to pass through the thicker portions of the gravel pack and sustain the desired sand filtering action prior to bitumen emulsion entering the wall openings.

Gravel pack 12 as shown, is preferably installed in a manner that it fills the forward space 14 of wellbore 11 between the bore end wall, and the end of liner 13. In effect the gravel pack will fill all paths along which hot bitumen will flow as it moves toward the liner.

To properly position liner 13 at a desired elevation within bore 11, the liner is provided with means for supporting it along its length at the desired elevation. Since the liner must be slid or pulled into bore 11 subsequent to formation of the latter, the support means includes a sled-like assembly 16 which depends from the lower end of the liner.

Sled or skid assembly 16 includes a plurality of spaced apart slide or track members 17 and 18 which contact the walls of the wellbore 11. Liner 13 can thereby be urged into the bore by being pushed downwardly from the surface. Alternatively, liner 13 can be pulled into place where a supplementary well is drilled to intersect the remote end of wellbore 11. Such method, however, constitutes a less convenient way to place the liner.

As shown in FIGS. 4, 5 and 6, skid assembly 16 includes said at least two tubular elongated slide members 17 and 18. These parallel members extend for substantially the horizontal length of liner 13 where it will be supported within the bore.

Since liner 13 may require a degree of flexibility to be properly positioned, skids 17 and 18 can be formed of tubular segments which are connected at a telescoping joint 19. This arrangement will permit both the liner and skids to readily conform with curvatures in the bore 11 during insertion.

The forward end of the respective skid members is bent upwardly to facilitate movement of the skid assembly through bore 11. The forward end will thus be precluded from digging into the bore wall, an action that could impede its forward movement while being urged into place.

A plurality of substantially vertical support braces 21 and 22 extend between, and are connected to the respective skids 17 and 18, and liner 13. The latter in turn is provided with a collar or a plurality of support pads 23 and 24 which engage the vertical braces.

A further lateral bracing member 25 is provided at the juncture between skid 17 and 18, and support brace 21 and 22. Said lateral element comprises a cross piece disposed transversely of bore 11, to space the skids as well as to support a liquid return conductor 26.

To add rigidity to the support assembly, each adjacent set of vertical braces 21 and 22 can be provided with intermediate stringers 27. The latter extend from

the skid member to the connecting pad of the next vertical brace.

Insertion of the liner 11 and skid assembly 16 will necessitate a limited degree of bending action in the liner as well as in the skid members. Stringers 27 between adjacent vertical members can be of the flexible type such as flexible cable or the like which would afford the necessary degree of movement. Further, the elongated skids 17 and 18 as noted can be segmented, affording them a degree of articulation. Thus, any bending of liner 13 will permit the skids to compensate by adjusting their length at joint 19. This flexibility between liner and skid avoids resistance to inward or outward movement of the liner through wellbore 11.

To facilitate introduction of gravel slurry into bore 11, skid assembly 16 is provided with at least one slurry conduit 28 and preferably with a second conduit 28'. These members are capable of conducting gravel slurry from the surface, down into the wellbore. Thus, slurry conduits 28 and 28' are releasably connected to skid assembly 16, or liner 13, prior to the latter being inserted into bore 11. To facilitate this movement, the forward end of conduit 28 is connected to the skid or to the wall of liner 11. The conduits will thereby be carried through bore 11 without being displaced. Thereafter, by releasing the conduits they can be withdrawn from bore 11 leaving skid 16 in place, while depositing the gravel slurry into the wellbore.

As the gravel pack is built up about the liner, conduits 28 and 28' are progressively withdrawn along the liner while the latter remains in place. Conduits 28 and 28' as shown in FIGS. 4 and 6 are supported by a transverse bracket or similar means. In one embodiment, the respective conduits 28 and 28' are connected by common strap 29 which extends across the top of liner 11 and is slidably supported thereon to permit both conduits to be simultaneously moved rearward with respect to the liner.

The gravel slurry as it leaves slurry pump 33, will normally comprise a mixture of gravel, together with a carrier fluid such as water. Means is provided therefore for removing the water after it has achieved its purpose. This will leave the gravel positioned about the liner 11 periphery, and yet not inundated. Where the formation is sufficiently porous to permit the water to drain off naturally, the induced drainage is unnecessary.

Toward evacuating water from borehole 11, at least one liquid return line or conductor 26 is provided on skid assembly 16. Line 26, similarly to the slurry carrying lines 28 and 28', can be detached from the skid assembly 16 after the latter is positioned. Thereafter it is progressively withdrawn along wellbore 11 as the gravel is deposited from the forward end of slurry conduits 28 and 28'. Return line 26 is provided with a screen 31 at the intake end thereof to minimize the ingestion of solids. Said line 26 is communicated with a pump 32 at the surface to promote the controlled withdrawal of the carrier liquid.

To permit withdrawal of line 26, the latter is slidably retained on lateral brace 25. Further, a flexible neck 34 depends from conduit 26 and is movable to facilitate such movement.

Operationally, installation of a gravel pack about any horizontal well liner in an unconsolidated, sandy environment is a prime consideration prior to the initial forming of the well. The composition of the gravel, particularly as to particle size, is best established after core borings and tests have disclosed the formation

composition at the well site. Having such information available, gravel within the desired size range can now be prepared for mixture into a water slurry.

Wellbore 11 is formed preferably with standard equipment by drilling downward through the overburden to the required depth at which the hydrocarbon is retained. Thereafter, the drill path is deviated into a horizontal direction within the productive layer.

At this point, a supplementary slanted or vertical well can be drilled to assist in placing liner 11 with its skid assembly 16. Preferably, however, liner 13 with attached skid assembly 16 is pushed into the bore from the surface.

Should a supplementary well be utilized, the forward or remote end of the liner can be connected to a cable which passes upward through the supplemental well. Thereafter the liner can be readily pulled into its desired position within bore 11.

The gravel slurry consisting of gravel, together with the water carrier, is introduced under pressure to the upper end of slurry conduits 28 and 28' by way of pump 33. As the slurry is discharged from the forward end of the respective conduits, the gravel progressively fills cavity 14 and the annular passage between liner 13 and wellbore 11 wall.

The aggregate gravel will accumulate into an unconsolidated mass, and the water will gravitate toward the lowest part of the wellbore 11. At the latter, the screened liquid return conductor 26 will fall to the floor of the bore and be in a position to aspirate and remove the water.

After a period of time, the gravel will be deposited to form bed 12, to a point where it blocks the forward end of the slurry conduits 28 and 28'. This condition will register at pump 32 by an indication of an increase in the back pressure on the slurry conduits.

Such a condition dictates the need to retract the respective slurry conduits 28 and 28' and to thereafter continue with the further deposition of the gravel. As the gravel progressively fills the space about liner 13, both the slurry conduits 28 and 28' as well as return line 26 will as noted be slidably withdrawn along their respective support members.

Over a period of deposition, gravel pack 12 will substantially fill and encircle liner 13, and drained water or carrier will be returned to the surface. Should the formation as noted, be sufficiently porous, slurry water can be permitted to drain into the formation rather than being withdrawn.

With the gravel pack 12 in place, the usual thermal stimulating or preheating of the formation can be commenced, by introduction of steam through liner 13. When the contained bitumen becomes flowable, it will carry an amount of sand with it toward liner 13. As the flow passes through gravel pack 12, the sand will be retained and allow passage of the hydrocarbon.

Although modifications and variations of the invention can be made without departing from the spirit and scope thereof, only such limitations should be imposed as are indicated in the appended claims.

We claim:

1. Well completion for a wellbore formed into a subterranean formation comprised of unconsolidated sand particles which releasably hold a viscous hydrocarbon, which wellbore extends substantially horizontally of and coextensively with said subterranean formation, which completion includes;

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an elongated perforated well liner registered in said wellbore and spaced from the walls thereof to define an annular chamber therebetween,

a gravel pack comprising an unconsolidated mass of particulated gravel which occupies said annular chamber to filter a flow of said viscous hydrocarbon liquid in which sand particles are entrained, and

well liner positioning means disposed in said wellbore and supportably engaging said well liner,

whereby at least some of said sand particles will be retained in the gravel pack to permit the passage of flowable hydrocarbon through gravel pack and into the perforated well liner,

said well liner support means including skid means having at least two laterally spaced apart, and longitudinally continuous skids resting on the wellbore lower wall, and support means extending upwardly from said continuous skids in supporting relationship to said well liner.

2. Well completion as defined in claim 1 wherein said well liner is positioned eccentrically of the wellbore.

3. Well completion as defined in claim 1 wherein said well liner is positioned adjacent to the wellbore upper wall.

4. Apparatus for forming a well completion within a wellbore formed into a subterranean formation comprised of unconsolidated sand particles which releasably hold a viscous hydrocarbon, which wellbore extends substantially horizontally of and coextensively of said subterranean formation, and which completion includes;

an elongated perforated well liner fixedly registered in said wellbore and spaced from the walls thereof to define an annular chamber therebetween, skid means depending downwardly from said liner and supportably positioning the liner relative to the wellbore,

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a gravel pack comprising an unconsolidated mass of particulated gravel which occupies said annular chamber to filter a flow of said viscous hydrocarbon in liquid form and within said sand particles are entrained,

conduit means slidably carried on said elongated perforated well liner for introducing a gravel slurry into said annular chamber to form said gravel pack,

and liquid removal conduit means operably carried on said skid means and having an inlet positioned adjacent to the lower wall of said wellbore to receive liquid from said gravel slurry.

5. Method for gravel packing a horizontal well completion formed into a subterranean formation comprised primarily of unconsolidated sands which hold viscous hydrocarbons in a manner to release said hydrocarbons when the subterranean formation is thermally stimulated, which completion includes an elongated well liner having at least one gravel slurry conduit operably depending therefrom, and a suction conduit operably positioned at the wellbore lower wall, which method includes the steps of;

positioning said elongated well liner in a wellbore formed horizontally into said subterranean reservoir, said well liner including at least one gravel slurry conduit which is removably held on the well liner, said gravel slurry conduit having a discharge opening disposed adjacent to the well liner remote end,

introducing a gravel slurry flow through said gravel slurry conduit whereby said slurry is deposited in said wellbore forward of the liner to permit gravel to accumulate about the liner,

withdrawing said gravel slurry conduit rearwardly along said liner as gravel builds up to enclose said liner, and

removing liquid from said wellbore lower wall through said suction conduit.

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[54] COMPLETION FOR TAR SAND SUBSTRATE

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[52] U.S. Cl. 166/50; 166/73;
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166/306, 67, 72, 73

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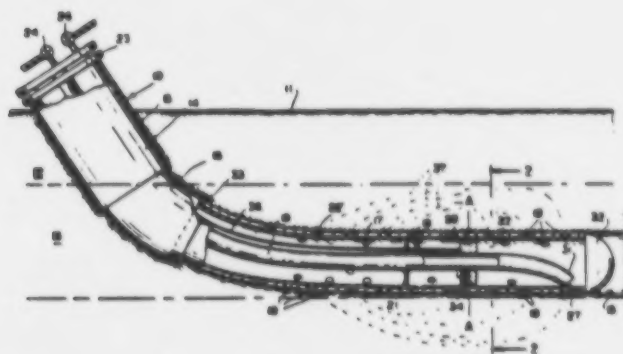
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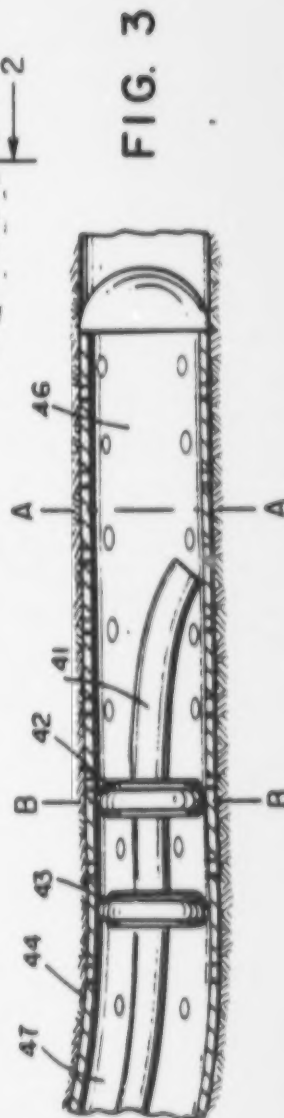
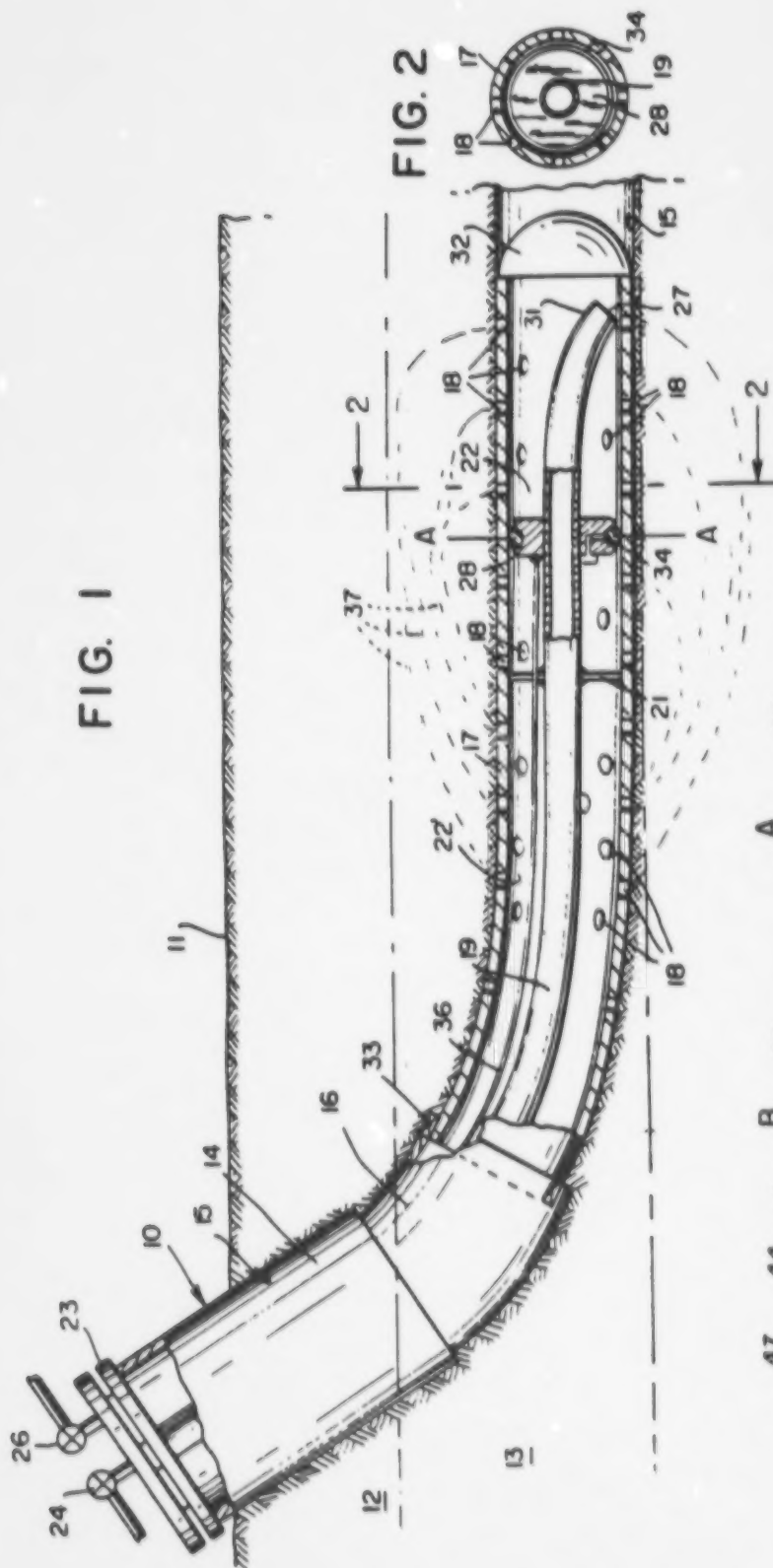
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ABSTRACT

Method and apparatus for recovering hydrocarbons from a subterranean formation in which a well completion, including a well liner, lies in a generally horizontal disposition within the hydrocarbon productive substrate. The liner encloses conductor means for delivering a stream of a hot stimulating agent to the well's remote or injection end, and means for regulating the production of bitumen emulsion from the producing end thereof. A fluid impervious barrier is movably interposed in the well liner between the injection end and the producing end to establish a pressure differential across said barrier thereby directing a flow of stimulating agent into the substrate. Said agent, by liquefying bitumen, creates a pattern of paths along which the mixture flows toward the well's lower pressure producing end. By progressively moving the barrier toward said producing end, the flow path pattern can be extended into a broader area of the substrate.

1 Claim, 3 Drawing Figures





COMPLETION FOR TAR SAND SUBSTRATE

BACKGROUND OF THE INVENTION

In the production of viscous hydrocarbons such as heavy crude, or bitumen from tar sands, it is necessary to thermally stimulate the relatively viscous hydrocarbon material such that it can flow and be withdrawn from the substrate as an emulsion. Usually, thermal stimulation comprises the introduction of hot aqueous heating mediums such as pressurized steam, into the substrate by way of an injection well to contact the bitumen.

This stimulating step over a period of time fluidizes the bitumen and releases it from the tar sand. The steam also establishes a pressure front whereby to urge the now flowable hydrocarbon emulsion or mixture toward one or more production wells.

The present method and apparatus are applicable to producing either bitumen from tar sand, or heavy viscous crude oil from a substrate. To simplify the following description, only bitumen will be referred to as the produced material.

Since the hot steam will condense under proper conditions, the product formed by the bitumen comprises in essence an aqueous mixture. Although said product could be considered as being an emulsion, depending on the condition thereof, it will be hereinafter referred to as an aqueous bitumen mixture.

In one method adapted to this type of viscous hydrocarbon production, it is found practical to utilize a single well which is sequentially heated, and produced on a cyclical principle. More specifically, the environment around the well is initially preheated to put the bitumen into a flowable condition. Thus during a soak period, heat is absorbed into the substrate about the well, causing the hot flowable material to gravitate toward the well. Thereafter, the stimulating step is continued in such manner that the hot mixture will continue to flow and to be produced from the well.

When over a period of time, pressure within the substrate deteriorates or the production flow decreases, it is necessary to recommence the cycle by further introduction of stimulating medium. As a sufficiently high pressure is reestablished and the bitumen solution is again caused to flow, steam injection is discontinued or minimized. Further controlled draw-down of the bitumen mixture can now be resumed.

This cyclical process can be continued indefinitely until the substrate adjacent to the well becomes exhausted of producible hydrocarbon product. Because of its general character, the method is referred to generally as the huff and puff process. It is found to function efficiently particularly when the stimulating medium is steam.

In an alternate method for producing viscous hydrocarbons from this type of substrate, a plurality of generally vertical wells are drilled in a desired surface pattern. Thereafter, stimulating fluid such as steam is injected for a period of time into the substrate through a centrally located injector well.

The heated or stimulated area about the well will be progressively widened, thereby establishing a pressure front which drives flowable bitumen mixture toward the surrounding producing wells. This process enjoys the advantage of being practiced by the continuous

introduction of the hot stimulating medium, and thus yield a continuous outflow.

It is now found desirable toward achieving an improved bitumen production rate, to utilize a generally horizontally disposed well for producing from a relatively thin hydrocarbon containing layer. Due to the nature of this type of well, the latter must as herein noted, operate on a cyclical basis to achieve an appreciable outflow of the bitumen mixture. Since cyclical operation amounts to a disruption of the producing phase it constitutes a less than economical expedient.

To realize an improved production rate from a horizontal well of the type contemplated, there is presently provided an efficient method and apparatus for producing a hot, aqueous bitumen mixture from a tar sand or similar environment. The process is effectuated through a single, elongated horizontal well which lies in at least a portion of a tar sand layer, preferably in a direction concurrent with the layer's direction.

Both the horizontal well itself and the adjacent substrate, are initially preheated to establish a favorable operating temperature at which fluidized bitumen mixture becomes mobile. The well includes means to establish a pattern of paths through the productive layer along which the bitumen mixture will readily flow. Said path thereby communicates a relatively high pressure injection area where the stimulating fluid is introduced, with a low pressure area in the well toward which the mixture gravitates.

Thereafter, and subsequent to the preheating step, the horizontal well is produced by regulated further introduction of a hot stimulating fluid. This latter injection, together with control of the well back pressure, causes fluidized bitumen mixture to be urged toward the well producing end. At high temperature conditions, all or a part of the stimulating steam will be produced with the mixture.

To maintain a favorable production output, the substrate is most effectively swept clean of removable bitumen by adjusting the injection pattern formed by the stimulating fluid path. The latter is achieved by diverting the flow of stimulating steam which penetrates the substrate, whereby to change the relationship between the high pressure or injection end of the liner, and the low pressure or production end thereof.

It is therefore an object of the invention to provide a method and apparatus for improving the production of viscous hydrocarbon fluid from a subterranean reservoir in which the hydrocarbon fluid is locked. A further object is to provide a method and apparatus for stimulating and producing a well aligned substantially horizontally in the formation, and containing a relatively viscous hydrocarbon. A still further object is to provide a method and apparatus for the continuous production of a viscous hydrocarbon fluid from a single well disposed substantially horizontally through a productive formation.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevation view in cross-section of a horizontal well of the type contemplated.

FIG. 2 is a cross-sectional view taken along line 2-2 in FIG. 1.

FIG. 3 is similar to FIG. 1 showing an alternate embodiment of the disclosed structure.

Referring to the drawings, a well 10 of the type contemplated is shown which enters the ground vertically, or preferably at an angle to the surface 11. Wellbore 13

is initially started through overburden 12 which overlies the productive or tar sand layer 13.

Thereafter, partway through the overburden layer bore 15 is deviated in a manner that at least a segment of the bore lies in a generally horizontal relationship with respect to the layer 13 as well as to the earth's surface 11. Further, the well's horizontal segment is preferably positioned at a depth whereby to be adjacent to the lower border of the generally horizontal, hydrocarbon containing layer 13. Following the usual drilling practices, wellbore 15 is provided at its upper end with a series of casing lengths 14 and 16 which are affixed in place.

An elongated liner 17 is inserted through the respective casings 14 and 16, and supported in casing 16 by a liner hanger 33. The latter is structured to permit passage of bitumen emulsion, or hot stimulating fluid there-through during the producing or injecting stages of the operation. Liner 17 can be provided at its forward or remote end with a bull hose 32 or similar means to facilitate its being slidably inserted into the wellbore.

Structurally, liner 17 comprises a steel, pipe-like member being perforated as required along that portion of the wall which lies within the tar sand layer 13. The perforations 18 can take the form of a series of holes in the liner wall. Alternately they can comprise slotted openings which extend either longitudinally or peripherally about the liner. Further, said perforations can be formed either before or after the liner is placed within the bore 15.

In any event, liner openings 18 are adequate to allow the discharge of heating medium therethrough and into the adjacent tar sand substrate 13. Further, they allow the return flow to the entry of a hot, aqueous bitumen mixture through the same wall openings after said mixture achieves a flowable state.

An elongated and carrying conductor or conduit 19 is disposed internally of liner 17. Conductor 19 can rest on liner 17 wall or it can be supported by spaced apart stabilizers 21 which attach to the conductor.

Conductor 19 is constructed of continuous tubing or alternately of pipe lengths which are interconnected end to end. Said conductor is capable of carrying a pressurized (about 200 to 500 psi) stream of hot stimulating fluid such as steam, hot water or either of said elements having appropriate chemicals intermixed therewith to facilitate the producing step. The condition of the injected fluid will depend on the composition of the substrate 13. Under particular circumstances, conductor 19 can also function to conduct hot bitumen mixture from liner 17.

Elongated conductor 19, if supported within liner 17, defines an annular passage 22, 22', for at least a part of the liner length. It can however rest directly on the conductor wall.

The upper external ends of the respective liners 17 and conductor 19 are provided with a closure means 23 such as a well head. The latter includes valves 24 and 26 which are operable to permit selective and or stropped communication of the individual liner passages with a source of stimulating liquid.

In one embodiment of the apparatus, to initiate production of emulsion the entire well completion is first preheated to adjust it to proper temperature and pressure conditions whereby to function within the tar sand substrate 13. This is achieved by connecting annular passage 22' to a source of the steam by way of valve 26. Concurrently, stimulating fluid such as steam at about

300 to 500 psi is introduced through well head 23 by way of valve 24, to elongated conductor 19. It is then conducted the full length of said conduit to the discharge opening 27 at the remote end thereof.

A first portion of the hot pressurized steam will enter liner 17, end chamber 31 and flow outwardly into the adjacent substrate 13 through perforations 18 in the liner wall.

A second portion of the steam flow will reverse its direction and be forced back along annulus 22 counter to the flow of the incoming steam in conductor 19. The steam will thereafter dissipate through openings 18 along a segment of the length of liner 17.

When steam is introduced by way of conductor 19 it progresses in a general upward direction through substrate 13 thereby fluidizing the bitumen and forming flow paths 37. Because of the lowered ambient pressure within liner 17 annular chamber 22', the emulsion will gravitate toward the latter.

During this preheat or soak period, the well's back pressure will have decreased considerably. The heating or stimulating fluid will nonetheless still pass from annulus 22' and enter the substrate 13 surrounding the liner 17 even though the steam is characterized by a reduced heating capacity.

Over a period of time, the soil in layer 13 surrounding well 10 will become preheated as the steam condenses. This will gradually put the contacted bitumen into a flowable emulsion. Due to the pressure drop of steam along annular passage 22', a pressure differential will be established between the well injection end and the producing end.

Further, steam which enters substrate 13 will, although exhibiting a tendency to flow upwardly, establish a progressively expanding heated area and heated paths 37 along which hot fluidized bitumen mixture can readily flow. Thus the flowable mixture will further gravitate to the lower pressured end of liner 17 and be thereafter urged toward well head 23.

When substrate 13 becomes sufficiently preheated, steam flow through the annulus 22' is discontinued and the hot stimulating injection is then maintained only through conductor 19. This heating step will emphasize liquefying of the bitumen at the well injection end, and further maintain the desired pressure differential in liner 17 between the producing and injection ends.

To promote and improve the flow of hot bitumen mixture through substrate 13, the well completion includes means whereby a definitive pressure drop is established between the injection end of the well, and a series of points along the well approaching the producing end. This objective is achieved by interposing a displaceable barrier 28 which is impervious to the flow of steam or stimulating fluid, in a manner to define and separate annular chambers 22 and 22'.

In one embodiment, barrier 28 comprises a packer of the type normally associated with well operations. The packer is operably positioned within liner 17 to support and locate conductor 19.

Barrier 28 however functions such that it can be slidably displaced along conductor 19 to a desired location therein and activated to expanded condition against the liner 17 wall whereby to maintain its location.

As a result, entering stimulating fluid such as pressurized steam, upon leaving the discharge end 27 of fluid conduit 19, will enter annular chamber 22. A major portion of the steam flow will as herein noted pass out-

wardly to penetrate the adjacent substrate 13 still having an elevated pressure and temperature.

Continued pressurized injection of the hot steam from conduit 19 will continue to melt the bitumen into flowable condition thereby further prompting its formation into a hot emulsion with steam condensate.

With the continued steam injection, the area of heated substrate will be progressively broadened particularly upwardly. Concurrently, elevated substrate pressures at the well injection end will urge the fluidized mixture toward the lower pressure production end of the well downstream of barrier 28 and into annulus 22', by way of the flow pattern formed by paths 37.

Eventually, the hot bitumen mixture in moving through the substrate toward the lower pressure production end of liner 17, will establish and widen the various flow paths 37. The bitumen mixture will then enter ports 18 of liner 17. At this point in the process, some of the injected steam may also enter liner 17 by way of the diverse flow paths, and will be produced through well head 23. By regulating the back pressure in annular passage 22', the flow of the hot bitumen mixture or emulsion to the well head 23 can be regulated. Alternatively, the hot emulsion can be pumped or otherwise withdrawn from the liner.

Toward achieving the desired optimum substrate penetration with stimulating medium, fluid impervious barrier 28 is positioned on and depends from conductor 19. Barrier 28 is initially located adjacent to the remote or forward end of conduit 19 and spaced from discharge opening 27. Barrier 28 in accordance with the invention, can assume any one of a number of embodiments which achieve a primary objective of functioning as a substantially impervious deterrent to fluid flow through annulus 22.

In one embodiment of the invention, barrier 28 comprises basically an annular body or bodies which extend from and which are fixed to conductor 19 by welding or by a suitable clamping means. Thus the barrier can be longitudinally displaced along liner 17 when conductor 19 is withdrawn through the well liner.

The barrier can assume the embodiment of a plurality of packers which are spaced apart and which include a torus-like peripherally expandable member 34. Such expandable members are well known and used in the petroleum producing industry for down hole operations. Physically, they are actuated through a hydraulic or pneumatic system represented by conduit 36 to radially engage the inner wall of liner 17.

As shown in FIG. 3, the barrier assembly comprises a plurality of expandable members 42 and 43. The latter are spaced apart and fixed on conductor 41 such that the entire assembly can be slidably adjusted as a unit along the inner wall of liner 44.

As in the previously described embodiment, the fluid barrier functions to segregate the liner into an injection end or chamber 46, and producing end or chamber 47. Displacement of the barrier along liner 44 from point A to point B, serves to lengthen chamber 46 and concurrently compress or shorten chamber 47.

Due to the nature of the liner's perforated wall, it is appreciated that barrier 28 will not necessarily form a completely fluid tight engagement therewith. The annular connection with the liner, however, will be sufficiently fluid tight to serve the present purpose.

Referring to FIG. 1, to be actuated from its contracted position into engaging condition, the expandable portion 34 of barrier 28 is communicated with a

controllable source of a pressurized gas such as air by way of conduit 36. The latter preferably extends along conductor 19 to well head 23.

To assemble the well completion 10 to a desired position within tar sand layer 13, wellbore 15 is first formed as herein noted. To follow one option, barrier 28 and conduit 19 are initially assembled within liner 17 prior to the latter being inserted into wellbore 15. The discharge end 27 of conductor 19 will thus normally be positioned adjacent to the liner 17 remote or injection end.

Thereafter, liner 17 is slidably urged along wellbore 15 until reaching its desired location. Thus, the discharge end 27 of conductor 19 will open into terminal chamber 31 defined by the wellbore end wall and barrier 28.

As herein described initial preheating of the well and its contiguous substrate is commenced during a soaking period of normally several weeks. After this preheating period, the stimulation step follows by injecting heated stimulant in a way that it will tend to flow from the liner injection end, toward the well's producing end.

Eventually the steam saturated segment of substrate 13 will become depleted of bitumen. This condition will normally be evidenced at well head 23 by production of steam and/or water, but little hydrocarbon product.

A desired level of emulsion production can be realized by increasing the number of, or by extending flow paths 37 in the substrate. This is realized by displacing conductor 19 from its initial position. Conductor 19 is thus withdrawn through well head 23, a sufficient distance to move barrier 28 toward the well's producing end.

This step is achieved by first actuating barrier 28 to its contracted position thereby freeing it from the surrounding conductor 17 walls. Conductor 19 and barrier 28 can then be pulled concurrently along liner 17 to the latter's relocated position. The repositioning of barrier 28 will in effect axially expand annular chamber 22, but decrease the size of the production annular chamber 22' by a comparable amount.

In its new location as shown in FIG. 3, barrier 28 (now represented in this FIG. 3 as barrier 42) is reactivated into expanded condition and the flow of steam through conductor 19 is continued.

This latter heating phase will extend the heated area of the substrate longitudinally toward the production end of the well. The effect of the barrier adjustment will be evidenced by an increase in the rate at which bitumen mixture is again produced at well head 23.

With the adjustment in barrier 28 from its initial position at A, to its second position at B, the rate of bitumen mixture will continue to increase. This increase reflects the entry of high pressure steam into the heretofore heated, but unproduced area of substrate 13 closer to the well's production end.

Consequently a new set, or extended set of hot flow paths 37 through substrate 13 will gradually be established as the new source of bitumen gradually melts and forms into the flowable mixture.

Production of the bitumen mixture will continue as herein noted until it again becomes evident by the excessive amount of steam and/or water leaving well head 23, that the expanded producing area has been depleted of bitumen.

Over a period of time, barrier 28 will be progressively retracted in a series of steps and repositioned along liner 17 until it approaches the producing end of the liner

where the latter leaves layer 13. At this phase of the operation, the substrate area or tar sand layer 13 will have been drained, or substantially depleted of its bitumen content. The horizontal well can thereafter be used as a stimulant injector along its entire length to facilitate production of adjacent wells which are disposed in the area.

The foregoing description for practicing the invention is essentially applicable when the stimulating medium is hot water rather than steam. Further, it can be appreciated that production of bitumen emulsion can be through the central conductor 19 and valve 24 at well head 23. In the latter instance, the hot stimulating medium can be introduced through valve 26 as is done during a preheating step. During this type of operation, the medium flow paths through the tar sand layer will move progressively from the higher pressured production end of the well, toward the remote end thereof.

Thereafter by drawing down the pressure at said well end, the emulsion will be withdrawn and produced through conduit 19.

Although modifications and variations of the invention can be made without departing from the spirit and scope thereof, only such limitations should be imposed as are indicated in the appended claims.

We claim:

1. A well completion for producing viscous hydrocarbons from a substrate layer comprising unconsolidated sand particles in which said hydrocarbon is releasably retained, which completion includes;

an elongated well liner 17 disposed in a wellbore 15 formed within the substrate layer 13, at least a portion of the well of said elongated well liner being perforated 18 and extending in a substantially horizontal disposition through said layer 13,

a well head 23 at one end of said elongated liner 17 and including;

fluid flow control valves 24 and 26,

fluid barrier means 28 carried on said fluid conduit 19 and being controllably displaceable within said well liner 17 to divided the annular passages 22 and 22' into injection and producing segments respectively at opposed sides of the barrier,

said barrier means 28 including;

a radially expandable element which is capable of being expandably actuated to engage the liner 17 inner wall,

barrier actuating means including a conduit 36 extending from the well head 23 to said radially expandable element, and means to selectively direct a stream of actuating fluid to said expandable element for urging the latter into the expanded condition and in engagement with the liner 17 wall,

said fluid conduit 19 being longitudinally adjustable within liner 17 to displace the fluid barrier means 28 to a desired location, and as said barrier means 28 operably engages fluid conduit 19 to be slidably adjusted therealong, and

displacement means engaging barrier means 28 to slidably adjust the position of the latter longitudinally within liner 17.

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United States Patent [19]

Schmidt

[11] Patent Number: 4,574,884

[45] Date of Patent: Mar. 11, 1986

[34] **DRAINHOLE AND DOWNHOLE HOT FLUID GENERATION OIL RECOVERY METHOD**

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[73] Assignee: Atlantic Richfield Company, Los Angeles, Calif.

[21] Appl. No.: 652,554

[22] Filed: Sep. 20, 1984

[51] Int. Cl.⁴ E21B 43/24

[52] U.S. Cl. 166/263; 166/30;

166/272; 166/901

[58] Field of Search 166/30, 59, 263, 272,
166/303, DIG. 1

[56]

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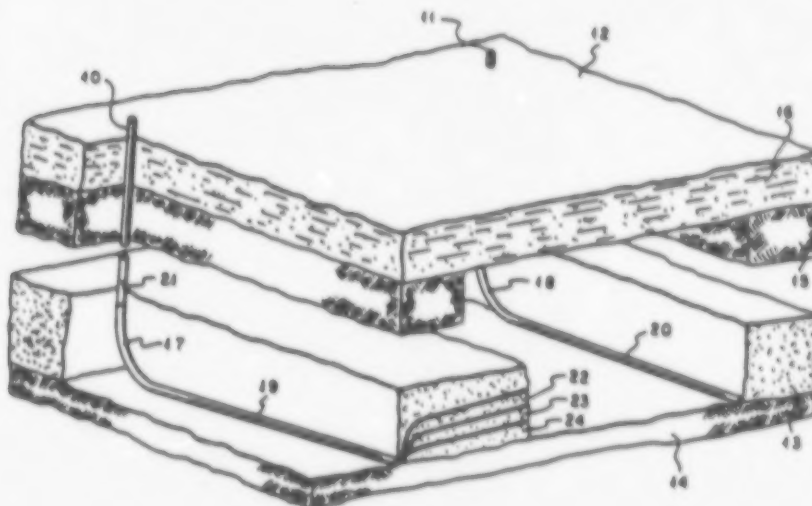
Primary Examiner—George A. Suchfield

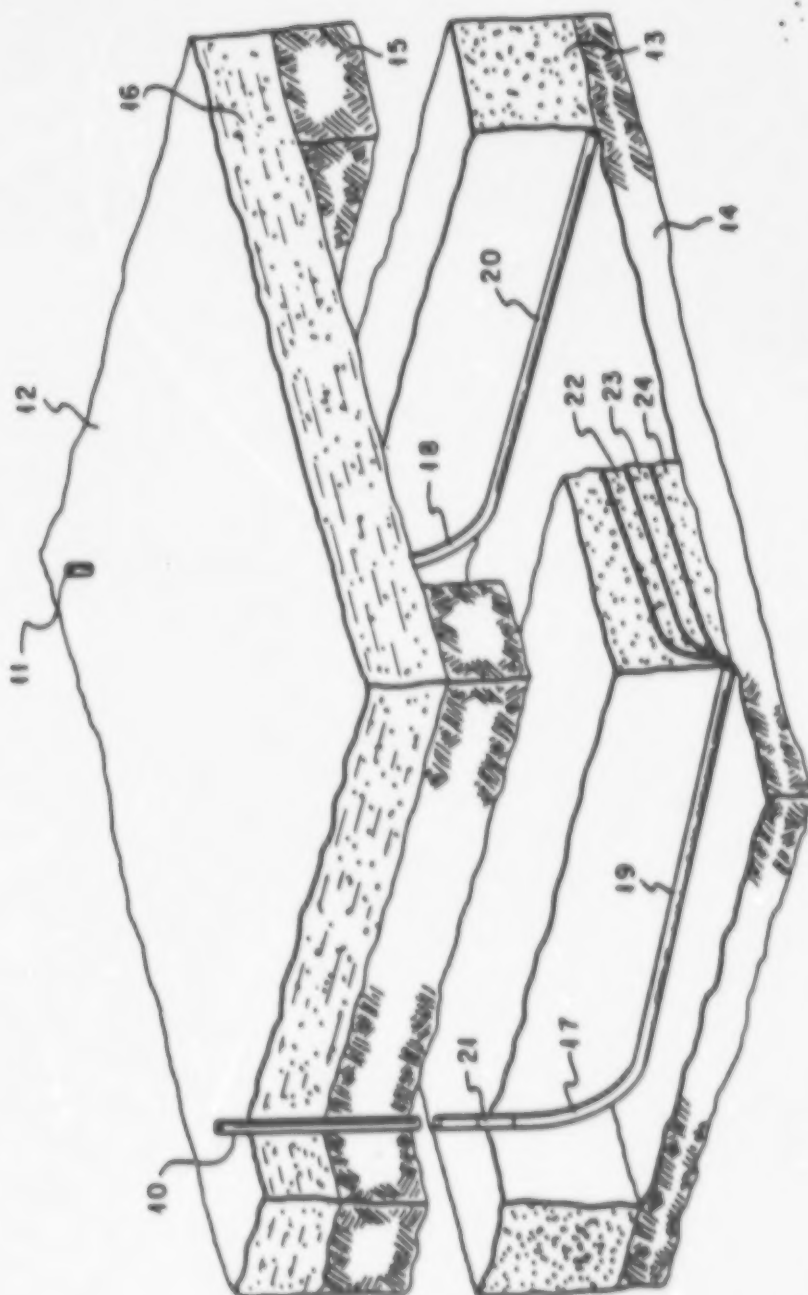
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ABSTRACT

Viscous oil is recovered by a process that increases sweep efficiency and heat and fuel utilization and that reduces well and compression requirements and costs. Initially, fluid pressure communication is created between two horizontal drainhole wells in a manner such that oil is produced during at least a part of the step of creating fluid pressure communication between the wells. Fluid pressure communication may be created by practicing hot aqueous fluid (preferably, steam) huff and puff techniques in one or both of the wells. After fluid pressure communication is created, a combustion supporting gas (probably, air), a fuel (preferably, natural gas) and an aqueous fluid (preferably, steam) is formed. The hot aqueous fluid and hot products of combustion are passed directly into the formation in horizontal line drive fashion. These hot fluids follow a horizontally wide sweep pattern which increases heat transfer to the inplace oil and increases oil drainage into the producing well. The process is especially useful in permafrost areas.

20 Claims, 1 Drawing Figure





DRAINHOLE AND DOWNHOLE HOT FLUID GENERATION OIL RECOVERY METHOD

BACKGROUND OF THE INVENTION

The present invention combines known techniques for stimulating oil recovery in a manner such that viscous oil recovery is increased and made economical. More particularly, viscous oil is recovered from a subterranean formation by means of downhole burning of fuel and hot fluid generation, passing the steam and products of combustion directly into the formation and creating line drive between horizontal drainholes.

In the recovery of oil from viscous oil-bearing formations, it is usually possible to produce only a very small portion of the original in place oil by natural or primary production. A wide variety of artificial recovery techniques, therefore, have been suggested for increasing oil recovery from these formations. For example, it has been proposed to inject gases into the formation to maintain the pressure of the formation and to decrease in a slight manner the viscosity of viscous oil adjacent the gas.

It has also been proposed to use steam stimulation for increasing oil production. Steam stimulation is the addition of thermal energy to a subsurface reservoir by injection of steam, usually of 60 to 90 percent quality. Steam injection has been practiced primarily as steam drive and as steam huff and puff. These techniques have been carried out with and without foaming, surfactant and caustic agents. In the steam huff and puff process, steam is injected into the formation for a period of time. Thereafter, injection is ceased and the well is backflowed, usually by pumping, to produce fluids from the formation. In one variation, the injection step is followed by a period of shut-in prior to producing fluids from the formation. This variation is called steam soaking. In general, steam is injected into the subsurface formation in quantities sufficient to heat a predetermined distance of the formation radially from the wellbore. This distance changes with time and with the number of huff and puff steps performed. Pressures commonly range between 500 and 2500 psi dependent upon the depth of the formation and the permeability of the formation. The steam is injected at a predetermined rate usually stated in pounds per hour or barrels per day of cold water equivalent, and may be injected for periods of a few days to six months and longer depending on the stage of production. In steam huff and puff (including steam soak), the total volume of reservoir heated is not large. Huff and puff through vertical wells is inefficient in formations of very low mobility and permeability. Huff and puff techniques through vertical wells are significantly limited and in many formations are not adequate for producing much of the oil in place.

It has been proposed to inject steam to drive oil toward a vertical production well. The steam displacing fluid travels from the injection well to the production well. The oil within the steam path is the only part of the oil that is produced. The shape of the path of the steam is called the sweep pattern. For vertical wells, at best the steam travels from the injection point to the production point. The steam sweeps a curvilinear path that resembles a pointed ellipse. The volume of the swept area divided by the total volume is called the sweep efficiency. Practical operations require good sweep sweep efficiency. Sweep efficiency or the height and minor axis of the pointed elliptically shaped sweep

pattern is dependent on a number of factors. Two factors are the mobility of the oil and the relative mobilities of the oil and steam. Other factors are the distance between the injection well and the producing well and the nature of the wells. The oil or petroleum in most relatively shallow viscous oil bearing formations is immobile until heated. The relative mobilities, densities and other factors cause the steam to override the oil, thereby decreasing the height of the the curvilinear sweep pattern. The mobility of the oil is so low that the minor axis of the pointed elliptically shaped steam path is small and the sweep pattern looks like a sliver or thickened line between the injection point and production point. Premature steam break through occurs and the steam does not lose its heat to the inplace oil. Moreover, the sweep efficiency is very poor. To improve sweep efficiency it has been proposed to drill a line of vertical injection wells and a laterally spaced line of vertical production wells and use a form of displacement called line drive. For line drive between vertical wells the number and costs of the wells required to accomplish the effects of line drive are excessive in viscous oil bearing formations.

In U.S. Pat. No. 3,960,214, it has been proposed to drill a horizontal drainhole in a viscous oil-bearing formation and to drill vertical production wells above and along the length of the horizontal injection well. This process is inefficient. The mobilized viscous oil tends to drain toward the lower part of the formation and the cost of the vertical production wells is excessive. The steam tends to channel through the oil and the sweep efficiency is low.

The steam for steam stimulation is usually generated at the surface of the earth and injected through an injection well from the surface. In U.S. Pat. No. 3,456,721, it has been proposed to use a downhole burner apparatus for generating the steam. A fuel is burned downhole with air and water is injected to contact and heat exchange with the flame to turn water into steam. Downhole steam generation has several advantages. The hot exhaust gases are cojected with the steam into the reservoir as opposed to conventional steam generators which exhaust to the atmosphere. Additionally, the exhaust gases maintain the formation pressure and add a certain amount of viscosity reduction to the oil. Adverse environmental effects on air quality are also reduced.

Some of the more extensive and valuable viscous oilbearing formations are found in areas covered by permafrost. Use of heat through an injection well creates problems in permafrost areas by thawing the area around the injection well.

It is an object of this invention to combine such known techniques in a manner such that many of the above-cited deficiencies associated with the known techniques and vertical wells are avoided or reduced. It is a further object of this invention to provide a viscous oil recovery process that is particularly useful and economical for remote areas, especially the remote areas of Alaska and similar areas where there is permafrost. It is still another object of the invention to provide a process wherein oil is economically produced during the first stage of the process.

SUMMARY OF THE INVENTION

This invention provides a process for recovering viscous oil from a subsurface formation. In the process,

sweep efficiency and heat and fuel utilization are increased and well and compression requirements and costs are reduced. In the first stage of the process, fluid pressure communication is created between two horizontal drainhole wells in a manner such that oil is produced during at least a part of the step of creating fluid pressure communication between the wells. Fluid pressure communication may be created by practicing hot aqueous fluid (steam, hot water, or mixtures thereof) huff and puff techniques in one or both of the wells. After fluid pressure communication is created, a combustion supporting gas (for example, air), a fuel (for example, natural gas) and an aqueous fluid are injected into one of the drainhole wells. The fuel is burned downhole in a manner such that hot aqueous fluid (steam/hot water) is formed downhole. The hot aqueous fluid and hot products of combustion are passed directly into the formation in horizontal line drive fashion from the injection well toward a producing second well. These hot fluids follow a horizontally wide sweep pattern which increases heat transfer to the in-place oil and increases gravity oil drainage into the producing well. The process of this invention requires less wells than the number of vertical wells required to achieve the same sweep efficiency.

This improved process is especially useful in permafrost areas because the steam may be generated below the permafrost and near the points of injection and because a horizontal well provides more formation contact with less vertical well surface. This vastly reduces permafrost thawing over conventional surface steam generation and injection through the permafrost by multiple vertical wells.

DESCRIPTION OF THE DRAWING

The drawing is a schematic perspective view showing two laterally spaced drainhole wells in a subsurface viscous oil bearing formation wherein oil is produced in accordance with the teachings of this invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

This invention provides a process for recovering viscous oil from a subsurface formation. The process combines known techniques in a manner such that overall sweep efficiency and heat utilization are increased and in a manner such that compression costs and well costs are reduced to the point that the process is economical for very low mobility oils. Increased sweep efficiency is accomplished by first creating fluid pressure communication between horizontal drainhole wells and producing oil during creation of fluid pressure communication, and by true line drive between a horizontal drainhole injection well and a horizontal drainhole production well, and by the way heated oil drains into the horizontal wells. Increased heat utilization is accomplished by downhole hot fluid generation, by use of all of the heat produced, and by the way the down-generated hot fluid and the products of combustion flow through the formation in an increased sweep pattern. Downhole hot fluid generation has the further advantage of permitting the generators to be used for gas lifting the formation fluids during production or backflowing cycles. Compression costs are decreased since the drive fluids are injected through less wells. Well costs are vastly reduced since two drainhole wells in line drive permits greater sweep efficiency with less

wells than required for conventional vertical well techniques.

Accordingly, in the drawing there is shown drainhole wells 10 and 11 laterally spaced from each other and extending from earth surface 12 into viscous oil-bearing subsurface formation 13. The oil in formation 13 is shown trapped in conventional fashion by relatively impermeable underlying formation 14 and by relatively impermeable overlying formation 15. For illustrative purposes, overlying formation 15 is shown uplifted from oil-bearing formation 13. This invention is especially useful in remote permafrost areas; therefore, overlying formation 15 is shown overlain by permafrost 16.

Drainhole wells have wellbores that deviate from a generally vertically oriented wellbore toward a more generally horizontal direction. Accordingly, drainhole wells 10 and 11 have curved intervals 17 and 18 and horizontal intervals 19 and 20, respectively. Drainhole wellbores may include more than one curved and more than one horizontal interval deviating from the same vertical wellbore. Various drilling assemblies or systems have been proposed for developing and drilling drainhole wellbores. For example, U.S. Pat. No. 3,394,804 describes a drilling system comprised of knuckle joint sections, a reamer and a drill bit which are turned at the surface by way of a drill string. In this patent, the initial deflection and direction of curved build interval is controlled by a deflecting tool or whipstock which in combination with the knuckle joints and forces on the drilling assembly causes the drill bit to cut into the wall of the vertical portion of the well, thereby tilting the common bit-reamer axis from the axis of the main borehole. As drilling is continued, the wellbore curves in the desired direction. Other types of drainhole drilling systems use downhole motors to turn the bit and reamer and bent subs or housings to generate the desired wellbore curvature. After the curved interval is completed, the drilling equipment is changed to drill a more stabilized interval generally horizontally oriented in oil-bearing formation 13. Drainhole wells 10 and 11 have the same orientation and horizontal intervals 19, and 20 extend in the direction to form continuous laterally spaced generally parallel lines. Preferably, these horizontal intervals are near the bottom of the part of the formation to be produced. The horizontal intervals are usually cased and are perforated along the longitudinal axis of the horizontal interval. In this manner, injected into one well will flow in a line sweep pattern if there is fluid pressure communication between the horizontal intervals.

After the drainhole wells are completed into formation 13, fluid pressure communication is created between horizontal intervals 19 and 20 in any conventional manner that produces oil during at least a part of the time that fluid pressure communication is being created. Fluid pressure communication means that when elevated fluid pressure is exerted and contained on the formation adjacent to one horizontal interval, the pressure in the other horizontal interval increases after a reasonable or practical period of time if the second well is shut-in. Preferably, fluid pressure communication between horizontal intervals 19 and 20 is created by steam huff and puff (including steam soak) techniques wherein steam is injected or passed into formation 13 through one or both horizontal intervals for a period of time. Thereafter steam injection is ceased. Hot water may be used if the viscous oil-bearing formation con-

tains materials like clay that react with steam and damage the formation permeability. Otherwise steam is preferred. Fluids including oil are produced from the formation through the horizontal interval used to inject steam into the formation. These huff and puff steps are repeated until the fluid pressure communication is created. Horizontal drainhole wells have unique advantages for this purpose. The amount of oil produced by huff and puff is vastly increased and makes the process much more economical. In vertical wells the flow path is like a sliver and quickly closes. Horizontal drain intervals allow a sort of line sweep pattern to develop which extends laterally and horizontally opening a more permanent thicker and greater volume fluid pressure communication path.

After fluid pressure communication has been created, the process of this invention utilizes downhole steam generation and hot fluid injection in horizontal line drive fashion between wells 10 and 11. Accordingly, in well 10 there is shown downhole hot fluid generator 21 which is located at a suitable downhole point, preferably near formation 13. A generator like that disclosed in U.S. Pat. No. 3,456,721 may be operated to generate hot water to superheated steam downhole. If formation 13 is in a permafrost area, downhole steam generation 21 will be located at a downhole point below permafrost 14. A combustion supporting gas (for example, air, oxygen or other oxygen-containing gases) and a suitable fuel (for example, natural gas, oil, residuum from a topping plant or other similar substance) are injected into well 10 down to hot fluid generator 21. Any desired pressure may be used which is suitable for the purposes hereinafter set forth. The fuel and combustion supporting gas are burned at the same time as aqueous fluid (for example, low quality steam, water, heated water or the like) is injected into well 10. The aqueous fluid quenches or heat exchanges with the flame and the aqueous fluid is converted to hot fluid (for example, superheated steam, high quality steam, steam and water, or hot water. Steam is much preferred due to its mobility and total heat-carrying properties, but hot water may be used if steam would damage the formation permeability. The hot aqueous fluid and hot products of combustion are passed at a pressure below the fracturing pressure of formation 13 from the downhole hot fluid generation point directly into subsurface formation 13, thereby utilizing all of the heat. In remote areas, there is usually a surplus of natural gas. Natural gas and air are the much preferred fluids. Natural gas is an especially efficient fuel for downhole steam generators. This system uses approximately 60% of the fuel by volume needed by surface generators to obtain the same reservoir heating effect.

The hot fluids enter the formation and due to the fluid pressure communication previously created and the line drive sweep path between horizontal intervals 19 and 20 of wells 10 and 11, respectively, the hot fluids transfer heat to the inplace viscous oil reducing its viscosity and rendering it mobile. The products of combustion tend to rise in a horizontal layer reducing the viscosity and increasing the mobility of oil remaining in the upper part of formation 13. Steam tends to rise in a horizontal by oriented layer following sweep path 23 a the steam transfers heat to the inplace oil and condensates. The heated oil tends to flow and drain downward and toward horizontal interval 20 of well 11 in a horizontal layer following sweep path 24 to horizontal interval 20 where the oil is produced to surface 12. Conventionally,

the oil is produced by pumping. But in this invention, downhole hot fluid generators may be placed in both drainhole wells 10 and 11 in formation 13 and the generators may be operated to produce steam for gas lifting or assisting pumping of the oil to the surface. Steam has the further advantage of preventing wax deposition. All of this is made possible only because fluid pressure communication has been previously created and the drain wells are horizontally oriented.

It is preferred that the downhole steam generator be used to also generate the steam for the hot aqueous fluid huff and puff steps used to create fluid pressure communication between the horizontal intervals of wells 10 and 11. As previously mentioned, a downhole steam generator (not shown) may also be placed downhole in well 11. In addition, hot aqueous fluid drive and production may be switched periodically between wells 10 and 11 if desired.

Various embodiments and modifications of this invention have been described in the foregoing description and examples, and further modifications will be apparent to those skilled in the art (for example, a series or pattern of drainhole wells may be employed). Such modifications are included within the scope of this invention as defined by the following claims.

I claim:

1. A method for producing oil from an oil-bearing subsurface formation comprising:

- (a) completing a first drainhole well wherein said first well has a horizontal interval extending into said formation from a vertical wellbore;
- (b) completing a second drainhole well wherein said second well has a horizontal interval extending into said formation from a vertical wellbore, said first and second drainhole wells being spaced from each other with said horizontal intervals extending in the same direction and orientation and at substantially at the same depth whereby said horizontal intervals are parallel to each other in substantially the same horizontal plane;
- (c) creating fluid pressure communication between said horizontal intervals of said first and second drainhole wells;
- (d) producing oil from said formation during at least a part of step (a);
- (e) injecting a combustion supporting gas, fuel and aqueous fluid into said first well;
- (f) burning injected fuel downhole in said first well at a downhole point in a manner such that aqueous fluid injected into said first well is converted to hot aqueous fluid;
- (g) passing the products of combustion and said hot aqueous fluid downward from the said downhole point directly into said horizontal interval to establish a horizontal line drive through the formation from said first well toward said second well, and
- (h) producing oil from said second well.

2. The method of claim 1 wherein in step (f) said hot aqueous fluid is steam.

3. The method of claim 1 wherein in step (e) said combustion gas is air and said fuel is natural gas.

4. The method of claim 3 wherein in step (f) said hot aqueous fluid is steam.

5. The method of claim 1 wherein said first of second wells are completed through permafrost and said downhole point is below said permafrost.

6. The method of claim 5 wherein in step (f) said hot aqueous fluid is steam.

7. The method of claim 5 wherein in step (e) said combustion gas is air and said fuel is natural gas.

8. The method of claim 7 wherein in step (f) said hot aqueous fluid is steam.

9. The method of claim 1 wherein in step (e) fluid pressure communication is created by sequentially injecting hot aqueous fluid into said formation by way of one of said wells for a period of time, ceasing injection of hot aqueous fluid, producing fluids from said formation through said well, and repeating said sequence until said fluid pressure communication is created.

10. The method of claim 9 wherein in step (e) said combustion gas is air and said fuel is natural gas.

11. The method of claim 10 wherein in steps (c) and (d) said hot aqueous fluid is steam.

12. The method of claim 10 wherein said first of second wells are completed through permafrost and said downhole point is below said permafrost.

13. The method of claim 12 wherein in step (e) said combustion gas is air and said fuel is natural gas.

14. The method of claim 13 wherein in steps (c) and (d) said hot aqueous fluid is steam.

15. The method of claim 9 wherein said first of second wells are completed through permafrost and said downhole point is below said permafrost.

16. The method of claim 15 wherein in step (e) said combustion gas is air and said fuel is natural gas.

17. The method of claim 16 wherein in step (f) said hot aqueous fluid is steam.

18. The method of claim 1 wherein in step (e) fluid pressure communication is created by sequentially injecting steam into said formation by way of both said wells for a period of time, ceasing injection of steam, producing fluids from said formation through both of said wells, and repeating said sequence until said fluid pressure communication is created.

19. The method of claim 18 wherein in step (e) said combustion gas is air and said fuel is natural gas.

20. The method of claim 14 wherein in steps (c) and (d) said hot aqueous fluid is steam.

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United States Patent [19]

Huang et al.

(11) Patent Number: 4,577,691

[45] **Date of Patent:** Mar. 25, 1986

- [54] METHOD AND APPARATUS FOR PRODUCING VISCOUS HYDROCARBONS FROM A SUBTERRANEAN FORMATION

- [75] Inventors: Wans-Sheng Huang; Sze-Foo Chien, both of Houston, Tex.

- [73] Assignee: Texaco Inc., White Plains, N.Y.

- [21] Appl. No.: 649,260

- [22] Filed: Sep. 10, 1984

- [51] Int. Cl.⁴ E21B 43/24; E21B 43/30

- [52] U.S. Ct. 166/263; 166/50;
166/57; 166/272; 166/303

- [58] **Field of Search** 166/263, 272, 302, 303,
166/30, 37

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Primary Examiner—George A. Suchfield

Attorney, Agent, or Firm—Robert A. Kulason; James J. O'Loughlin; Robert B. Burns

[57] ABSTRACT

Method and apparatus for thermally stimulating bitumen and other viscous hydrocarbon products from a subterranean formation in which the product is held. A plurality of wells are formed in the layer, which wells extend from the surface into a generally horizontal direction through the productive subterranean layer. The respective wells are spaced vertically apart whereby a thermal stimulating fluid such as steam can be selectively injected into discrete segments of the layer. Such injection will achieve the most effective sweeping action by the stimulating fluid through the productive layer. There results an orderly downward flow of the produced product and a more uniform and efficient distribution of heat in the stimulated formation.

8 Claims, 4 Drawing Figures

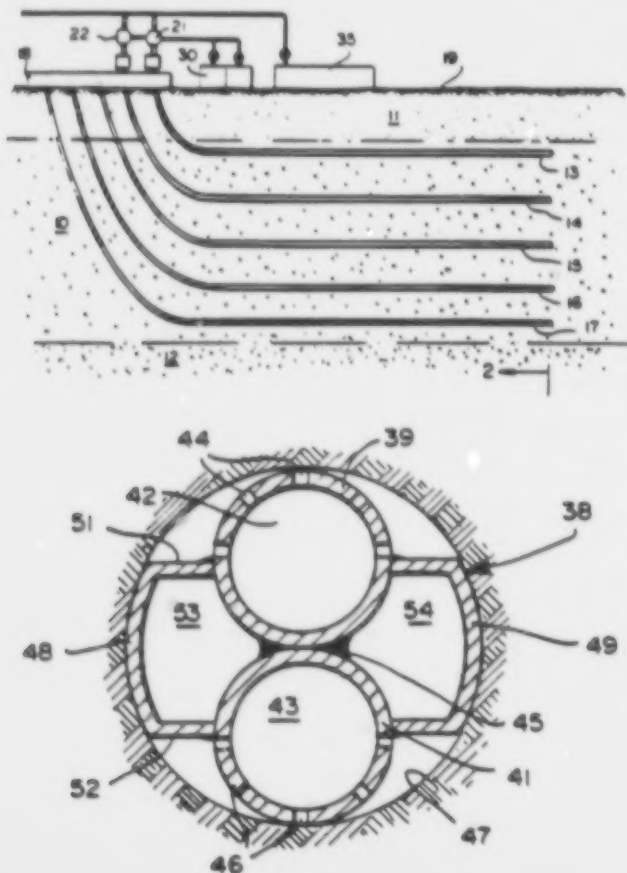


FIG. 1

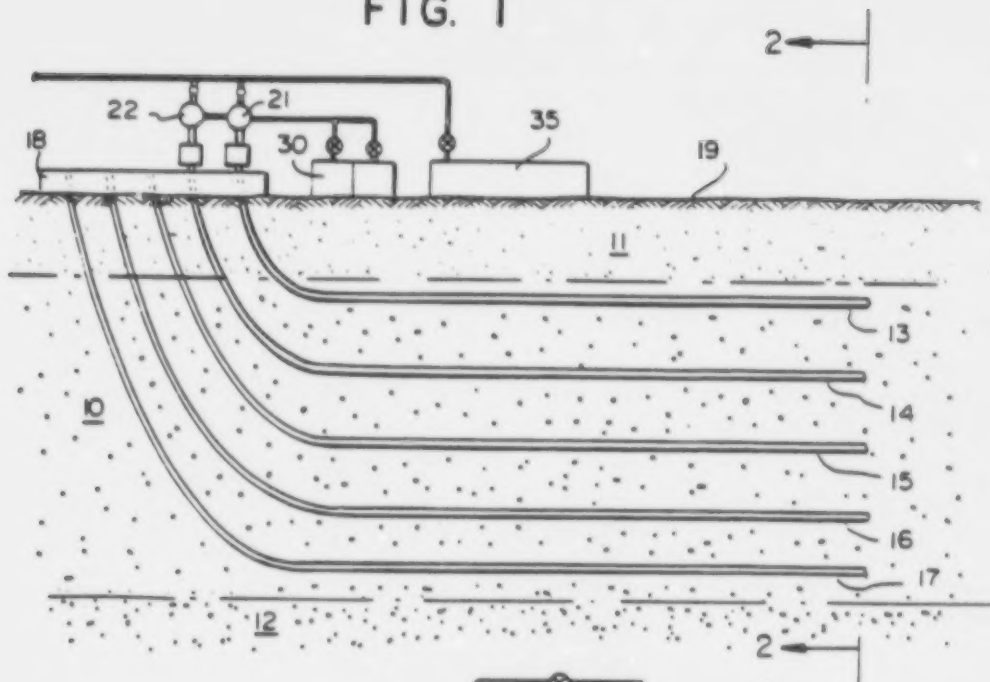


FIG. 2

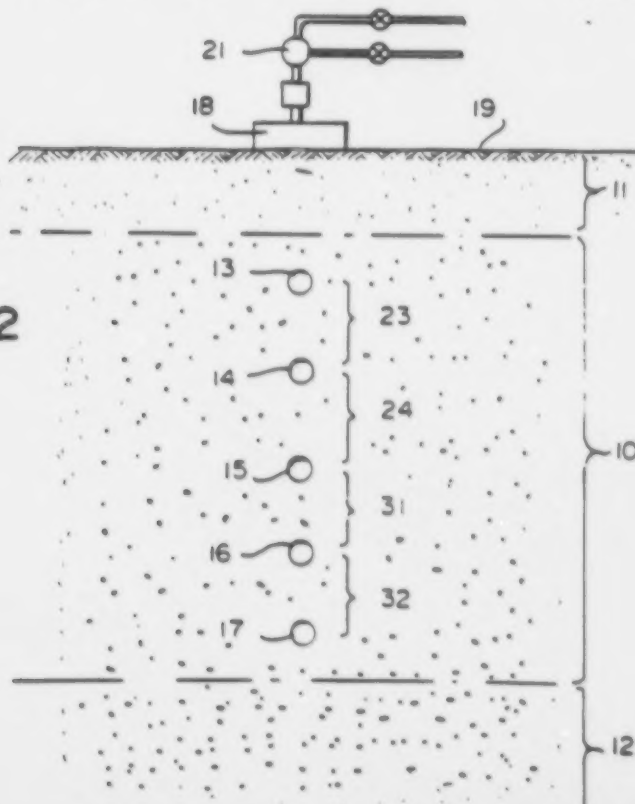


FIG. 3

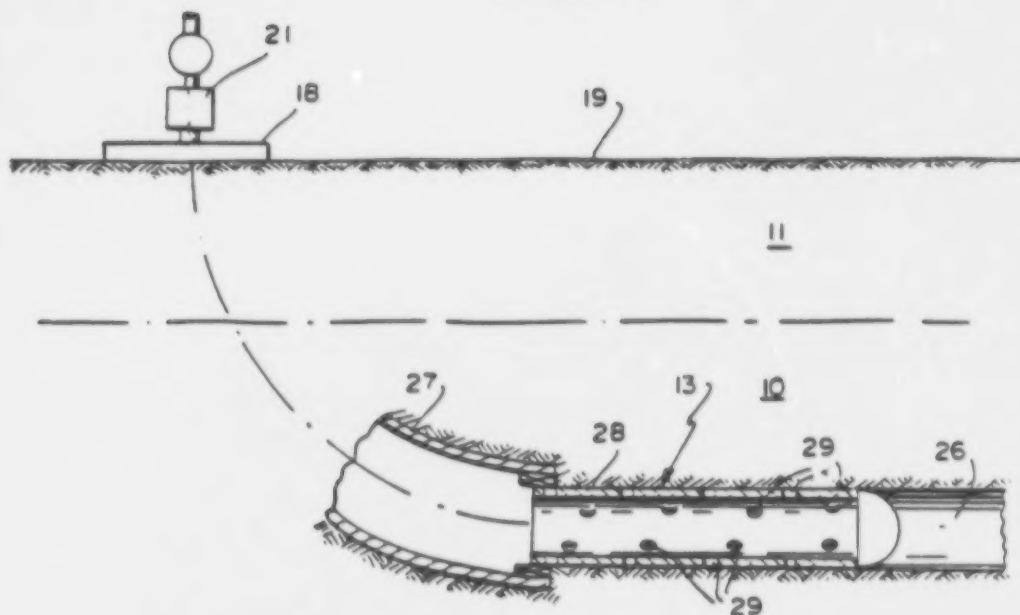
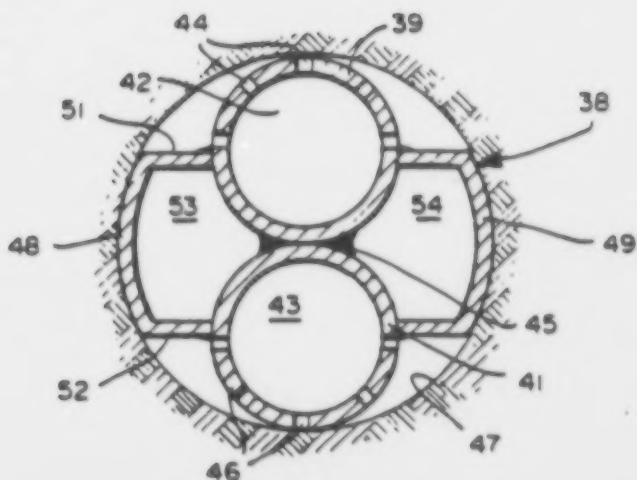


FIG. 4



METHOD AND APPARATUS FOR PRODUCING VISCOUS HYDROCARBONS FROM A SUBTERRANEAN FORMATION

BACKGROUND OF THE INVENTION

In the extraction of viscous hydrocarbon products such as crude oil from a subterranean reservoir or formation, production is often hampered by a number of factors. These include the inability of the gas pressure in the formation to urge the viscous product to the surface. Similarly, in the production of bitumen from a tar sand substrate the viscosity of the bitumen is such that it is virtually immovable while retained in its in situ state.

Toward facilitating the production of these viscous hydrocarbon products, methods have been provided to lessen the viscosity of the retained products and to promote their movement through the substrate and toward a producing well.

In the instance of bitumen contained within tar sand formations, the latter can be relatively thin in comparison to the normal subterranean reservoir wherein crude oil is retained. A productive layer, however, even though comprised of tar sands, can be hundreds of feet in thickness. It has therefore become practical when extracting bitumen or crude oil from such a layer, to utilize horizontal rather than vertical or diverter type wells.

In such an installation, the well or wells are spudded into the substrate in such manner as to approach the overburden layer either vertically or at an angle. Thereafter, as the wellbore enters and penetrates the productive layer, it is diverted into a substantially horizontal direction. Preferably, the wellbore will be urged in a direction such that it will run concurrently with the productive layer.

With the or more horizontal wells formed into a productive layer, it is possible to use at least one of the wells for injecting a hot stimulating fluid. The latter usually comprises water or steam which are forced into the formation. In either instance, contact between the hot stimulating medium and the hydrocarbon will gradually transform the latter into flowable condition.

Steam, with or without additive materials, is often utilized as the stimulating medium. Thereafter, the resulting hot condensate will form an emulsion with the flowable hydrocarbon and be in producible form.

As a general practice, thermal stimulation of a productive layer is initiated by first raising the environment of the well or wells to a temperature at which the viscosity of the contained hydrocarbon is reduced. Thereafter, further injection of pressurized steam will urge the flowable hydrocarbon emulsion toward a lower pressure producing well or toward a lower pressure portion of the single well.

If a single well is used, the huff and puff method for producing can be employed by alternately injecting hot stimulating fluid selectively into the well. Thereafter, a pumping procedure extracts the emulsion from the well for further treatment and separation.

In the instance of a productive substrate which covers a great depth, a considerable amount of steam can be used before the hydrocarbon is produced. In other words, when steam is injected into an expansive productive layer that runs for a considerable depth, much of the steam will be dissipated and wasted. Further, in such an instance, there is presently lacking a feasible

way of accurately determining the extent to which the production layer is being heated and produced.

As in any operation where hydrocarbon is produced from a subterranean formation, it is a primary objective to remove the greatest amount of product while using a minimal amount of stimulating medium. It is thus mandatory, in order to achieve a higher degree of efficiency, that the bitumen or the hydrocarbon containing layer be swept or penetrated in a manner that the maximum amount of hydrocarbon is removed with as little wasted heat as possible.

This objective is achieved as hereinafter described, by the particular disposition of wells within a productive layer whereby to regulate the flow and function of a stimulating medium which is injected into the formation.

There is presently disclosed a method for producing a viscous hydrocarbon such as bitumen or crude oil from a subterranean layer or formation by a plurality of wells or preferably from a well array. The latter is formed in said layer in a manner such that the respective wells lie in a substantially horizontal alignment, vertically spaced, and positioned at different levels or depths.

The respective wells preferably originate from a common area or pad at the surface. They thereafter penetrate the overburden, and are diverted into a substantially horizontal direction through the productive layer. Production of hydrocarbon emulsion thereafter results by virtue of the selective introduction of a hot pressurized stimulating fluid in a manner that the productive layer will be most effectively swept and drained of the contained hydrocarbon.

To most effectively sweep a formation, and optimize the usage of steam, a plurality of horizontal wells are formed as noted, in substantially vertical alignment. The wells are spaced to define a series of contiguous, horizontal formation segments therebetween. The latter in effect are striated by the respective parallel wells.

Thereafter, selective introduction of a heating medium into the various wells progressively heats the contiguous segments and results in an orderly, efficient downward flow of the hydrocarbon in emulsion form. As each parallel segment is heated and produced, the next lower adjacent segment is similarly treated and produced.

It is therefore an object of the invention to provide an efficient method to thermally stimulate a subterranean formation for the production of viscous hydrocarbons therefrom.

A further object is to provide a method for the stimulation of a viscous hydrocarbon containing substrate in a manner to cause an orderly downward flow of hydrocarbon emulsion into a producing well.

Another object is to provide an array of horizontally disposed, and vertically spaced apart wells within a subterranean productive layer, which arrangement will assure the most efficient extraction of hydrocarbon product in response to the introduction of a hot stimulating fluid into the substrate.

A still further object is to provide a method and an arrangement of wells in a tar sand formation for producing bitumen emulsion sequentially from adjacent horizontal segments of the productive layer.

DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a vertical cross-sectional segment of a productive formation including a plurality of wells

having portions thereof disposed in a general horizontal direction.

FIG. 2 is an end view of the formation taken along line 2-2 in FIG. 1.

FIG. 3 is a segmentary view on an enlarged scale of one of the horizontal wells shown in FIG. 1.

FIG. 4 is an alternate embodiment of a well liner applicable to the instant method.

In achieving the above objectives, the instant method provides firstly an arrangement or array of wells disposed within the hydrocarbon containing formation or layer. The respective wells pass either vertically or at an angle through the overburden which covers the productive layer. Thereafter, as the wellbore approaches the productive layer it is diverted to advance in a substantially horizontal direction preferably concurrently with the direction of the layer.

The respective parallel wells function to delineate a series of horizontal productive segments within the productive layer. Each segment can thereafter be individually thermally treated and produced.

As the upper segment of the formation is produced, an aqueous cap is applied thereto to preserve the thermal character of the substrate. The cap will further fill the voids which have been formed by removal of the hydrocarbon from said segment.

The various wellbores are drilled into the productive layer and provided with completions generally in the form of metallic liners. The latter are preferably perforated to permit the egress of steam, and the ingress of hydrocarbon emulsion. Thereafter, the selective introduction of hot stimulating fluid to particular wells causes the well and its immediate environs within a discrete segment, to be further heated. This will force hot hydrocarbon emulsion downwardly into the well at the lower side of said discrete segment.

When a treated layer segment has been substantially exhausted of hydrocarbon emulsion as witnessed by the rate of production at the surface, the next lower or contiguous horizontal segment will be similarly treated and produced. Over a period of time each of the respective horizontally defined productive segments will be treated in turn. The thermal treating steam is thereby most effectively utilized and the hydrocarbon emulsion follows a generally downward progression to be produced from a well at the lower side of each segment.

Referring to the drawings, and to achieve the instant method, an array of wells as presently contemplated, is shown in FIGS. 1 and 2 positioned in a subterranean productive layer 10. For the present description, the productive substrate or formation will be considered to be a layer which can range in thickness from about 50 to several hundred feet. Where the productive layer is of such a magnitude as herein mentioned, a plurality of vertically spaced well completions are installed to achieve the desired striating of the formation into horizontal segments in which the various wells comprise the strata.

The present method as herein mentioned can be addressed to the production of a number of forms of viscous hydrocarbons. To simplify the description, however, reference will be hereinafter made only to the production of bitumen or bitumen emulsion from the productive layer 10 by steam injection.

Said productive layer 10 is normally comprised of an earthen material typified by tar sands as found in the Athabasca area of Canada. In such a substrate, a large part of the composition includes unconsolidated sands.

The sand particles function to retain the bitumen in such a condition that the latter cannot be readily displaced or separated.

It is known, for example, that for producing bitumen it is necessary to thermally stimulate the product flow by introduction of steam into the substrate at such a pressure that it is forced into the formation. Steam, as a matter of practicality, is introduced at a sufficient pressure at the well head to penetrate the substrate adjacent to the respective wells. Thereafter the steam condensate will form a hot emulsion or mixture with the softened bitumen.

Productive layer 10 is generally, although not necessarily, covered with an unproductive overburden 11 which can extend for a relatively minimal distance or for several hundred feet in depth. In a similar manner, an underlayer 12 beneath the productive layer, comprises in effect an area which is lacking in the hydrocarbon product. Thus, the respective upper and lower areas which encompass tar sand layer 10 constitute non-definitive borders or edges to said layer.

As shown in FIGS. 1 and 2, tar sand layer 10 is provided with a plurality of horizontally arranged wells 13 to 17 inclusive. The respective wells extend for a distance of several hundred feet to most effectively achieve the maximum degree of efficiency and the subsequent downward sweeping action of steam through the layer. The number of vertically spaced wells actually needed will be a function of the overall thickness of productive layer 10 and the composition of the formation.

Upper well 13 is preferably commenced at a pad or central location 18 at surface 19. Said well is provided with the normal well head equipment 21. The latter functions to control the introduction of stimulant thereto and the subsequent removal of hot bitumen emulsion therefrom on a producing cycle.

The respective wells 13 to 17 inclusive as shown in FIG. 2, are spaced vertically apart to define a series of discrete productive segments such as 23 and 24 within the substrate therebetween. In such an arrangement, the respective productive segments are sequentially heated and produced one at a time. By thus limiting the volume of the productive area which is heated and produced, the heating medium is utilized to optimal efficiency.

Commencing of well 13 can be initiated at surface 19 in either a vertical direction or preferably at an angle offset from vertical to achieve penetration of overburden layer 11. Thereafter, as the wellbore enters the upper end of the productive layer 10, it is deviated by one of the usual methods to assume a horizontal alignment. Thus, well 13 extends concurrently with the tar sand layer in a direction usually parallel to the earth's surface.

The bore of second well 14 is likewise commenced at pad 18 and is also provided with a well head 22 to regulate passage of produced fluids and stimulating medium through said well. Well 14, as noted, is formed in a manner similar to first wellbore 13. The second wellbore, however, is diverted into a horizontal direction only at such time as it has reached a desired depth, and is vertically spaced below well 13.

In effect, the vertically spaced horizontal wells 13 and 14 are positioned to define the discrete productive segment 23 therebetween.

Thereafter, wells 15, 16 and 17, or as many more wells as required, are formed into layer 10 to define additional horizontal segments 31 and 32. By the selec-

tive and individual heating and producing of the respective segments, starting at the uppermost, downward flow of bitumen emulsion can be withdrawn sequentially from the respective wells in descending order.

A completion of the various wells as shown in FIG. 3, comprises basically a lengthy surface casing 27 which is cemented into wellbore 26, and extends upwardly to pad 18. A perforated liner 28 is thereafter inserted into the horizontal portion of the wellbore and engaged with surface casing 27 to conduct pressurized stimulating fluid into the productive, segment area adjacent thereto. The respective wells, as shown in FIG. 1, are manifolded to a source of steam 30 and to bitumen storage means 35.

A standard form of well liner 28 comprises generally a metallic cylindrical element such as a pipe, casing or the like. Said member further embodies a series of wall perforations 29 which can be either holes, or narrow slots, sufficiently large to permit the discharge of stimulating fluid. They will also be of a sufficient size to readily receive the flow of hot bitumen emulsion which will gravitate toward the lower wells.

Perforations 29 in the well liner 28 wall can be performed prior to liner 28 being registered within wellbore 26. However, said perforations can, by use of 25 known perforating equipment, also be formed subsequent to installation of the liner within the bore.

Operationally, to commence production of bitumen emulsion from tar sand layer 10, and particularly from uppermost segment 23, the area between and about the respective wells 13 and 14 is initially preheated to a minimal predetermined temperature. The optimal temperature will depend on a number of factors including the composition of the substrate as well as the underground temperature.

As injected steam causes the bitumen in horizontal segment 23 to become less viscous, it mixes with hot condensate into a flowable bitumen emulsion. This preheating period can extend over several weeks or even months and will substantially increase the pressure within said horizontal segment 23.

After the initial preheating of segment 23, introduction of steam through well 14 is discontinued. However, steam introduction is continued through well 13 and initiated in well 15. Since the pressure in well 14 will now be abruptly decreased, the flow of hot bitumen emulsion into the intermediate well 14 will commence.

Thereafter, steam injection by way of well 13 will continue until it becomes apparent from the emulsion production rate at well 14, that segment 23 is substantially depleted of its bitumen content.

This factor will become evident by the added outflow of steam through well head 22 at producing well 14. This indicates that steam is passing through the voids and channels created by the exiting bitumen. The further introduction of steam will be wasteful and unproductive.

During this heating and producing period, steam introduction has been initiated, preferably at a lower pressure than steam into well 13, by way of well 15 to heat the next lower contiguous horizontal segments 24. However, with the end of the bitumen production through well 14, water is introduced by way of well 13 to form a liquid cap on the uppermost horizontal segment 23. The inflowing water will as noted occupy the voids and the channels created in the formation by the outflowing bitumen. Further, the injected water will tend to sustain the formation pressure therebeneath.

When the liquid or water cap has been applied to segments 23, pressurized steam injection will again be commenced by way of well 14 to enter segment 24. This is in anticipation of a producing step whereby the downflowing bitumen from segment 24 will be extracted. Since said segment 24 has received a degree of initial preheating during the previous producing step, the present heating from upper well 14 will prompt further bitumen emulsion formation.

By reducing the pressure at well 15 at the lower edge of segments 24, bitumen will be produced at said well while concurrently heating of the next lower horizontal segment 31 will be commenced. Over a period of time, as formation segment 24 is produced through well 15, the next lower adjacent segment 31 will be subjected to preheating by way of well 16.

As each successive horizontal formation segment becomes depleted of bitumen, the upper liquid cap will be applied through the well at said segment upper edge. However, since steam is introduced to the lower edge of the horizontal segment the steam will be confined so that its use is most effectively applied rather than having it dissipated over a larger productive area or through the depleted upper formation segments.

A preferred method for assuring production from a formation by horizontal segments, utilizes directional introduction of the hot steam and the subsequent water. One embodiment of a well liner which is capable of handling both the stimulating and production functions, is illustrated in FIG. 4.

As shown, well liner 38 includes a plurality of elongated conductors 39 and 41 disposed one above the other to define flow passages 42 and 43. Each of said elongated conductors is provided with a plurality of ports or openings 44 and 46 formed in the respective walls.

Conductors 39 and 41 are joined along their length at a welded joint 45 to form a unitary member. Upper conductor 39 includes openings 44 which are aligned in a general upward and outward direction along a limited radial segment of approximately 180° of said conductor's wall.

Openings 46 formed in the lower wall of lower conductor 41 also are aligned to direct steam or water in an outward and downward direction. Thus, pressurized steam and water flows which issue from the respective conductors, will assume a desired direction.

To facilitate registering liner 38 within a horizontal borehole 47, the dual conductor arrangement is formed so that the upper and lower surfaces of conductors 39 and 41 respectively will slidably engage the borehole corresponding walls. Further, well liner 38 is provided with lateral protrusions in the form of side panels 48 and 49. The latter extend outwardly of the liner, having a curved peripheral edge which substantially conforms to, and slidably engages the borehole 47 walls.

Each lateral panel, 48 for example, is comprised of upper and lower connector elements 51 and 52 which extend inwardly to engage and depend from a conductor wall. Said panels 48 and 49 are welded to the respective conductors at elongated seams to in effect define closed compartments 53 and 54 which are capable of receiving and conducting bitumen emulsion flow.

To maintain the thermal quality of steam used in the formation stimulating function, compartments 53 and 54 can be provided with tracer lines to conduct a flow of steam therethrough. Thus, the temperature of the entire liner 38 can be maintained at a preferred operating level.

during the heating phases. Said elevated temperature will be sufficient to sustain the thermal quality of the steam along its path prior to injection into the formation. It will further maintain a heated path along which bitumen emulsion will flow as it is conducted toward the well head thereby to assure fluidity of the emulsion.

To foster reception of hot bitumen emulsion into liner 38, upper conductor connector member 51 as shown is tilted downwardly toward the seam at conductor 39 wall. It thus terminates adjacent to and beneath wall ports 44. The downwardly flowing hot bitumen emulsion from the formation will therefore be channelled toward the lower pressure passage 42 during a producing cycle when the formation segment above said conductor 39 has been stimulated.

It is appreciated that while the disclosed well liner does constitute a preferred embodiment of a dual conductor member, adapted to the present process, similar embodiments can be utilized without departing from the spirit and scope of the invention.

It is further understood that although modifications and variations of the invention can be made without departing from the spirit and scope thereof, only such limitations should be imposed as are indicated in the appended claims.

We claim:

1. Method for thermally enhanced production of a viscous hydrocarbon from a productive layer of a formation in which the hydrocarbon is releasably held, whereby selectively heat discrete segments of the formation to increase the viscosity of said hydrocarbon fluid, said method includes the steps of, forming in said formation a plurality of substantially parallel well completions which extend in a generally horizontal direction and which are vertically spaced apart one from the other to define a series of contiguous horizontal formation segments striated by the respective well completions, selectively introducing steam to the upper one of said contiguous horizontal formation segments whereby to release hydrocarbon fluid therefrom and to enhance the downward flow of a hot hydrocarbon emulsion, and producing said hydrocarbon emulsion from said horizontal well completion positioned at the lower side of said upper horizontal formation segment, and thereafter individually heating said discrete horizontal formation segments one at a time in descending

order, and producing emulsion from each of said horizontal segments by way of the well completion immediately below the heated segment.

2. In the method as defined in claim 1, including the step of;

preheating the next lower horizontal formation segment to a formation segment thereabove which is being produced, concurrently whereby to initiate fluidization of the hydrocarbon fluid in said next lower horizontal segment.

3. In the method as defined in claim 2, including the step of;

introducing a liquid medium into the upper side of said horizontal formation segment to define a fluid cap for heating medium being introduced to the horizontal segment immediately therebelow.

4. In the method as defined in claim 3, including the step of; maintaining said liquid cap on the productive layer as each succeeding horizontal segment thereof is produced.

5. A well liner for insertion into a horizontal extending well bore within a productive formation which releasably holds a viscous hydrocarbon, to release the hydrocarbon by thermal stimulation through the introduction of a hot pressurized heating medium into said formation, which well liner includes

a plurality of discrete conductors disposed one above the other, that are capable of selectively directing said pressurized heating medium into the formation, and of conducting the hydrocarbon emulsion therefrom,

perforations formed in the walls of said discrete conductors,

lateral panels which depend from and commonly engage the respective conductors, each of which panels includes a contoured wall positioned to slidably engage the adjacent well bore wall during insertion of the liner into said well bore.

6. In the apparatus as defined in claim 5, wherein the respective lateral panels define longitudinal passages along opposed sides of said well liner.

7. In the apparatus as defined in claim 6, wherein said longitudinal passages are provided with means for introducing a heating medium thereto.

8. In the apparatus as defined in claim 6, wherein said longitudinal passages are provided with means for circulating a heating medium therethrough.

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(54) Solvent Flooding to Recover Viscous Oils

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SOLVENT FLOODING TO RECOVER VISCOUS OILS

This invention is directed to a method of recovering oil from viscous oil-containing subsurface formations. More particularly, this invention is directed to a hydrocarbon solvent recovery method for recovering oil from subsurface formations that are penetrated by at least one injection well and one production well which extend downwardly from the surface of the earth into the bottom of the oil-containing formation and then extend horizontally through the formation.

In U.S. Patent No. 4,373,585, J.L. Fitch et al., issued February 15, 1983, there is disclosed a method of recovering viscous oil from a viscous oil-containing formation wherein a selected solvent is injected into a fluid communication path in the lower portion of the formation intermediate at least an injection well and a production well. A hydrocarbon solvent having a density less than oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions is injected into the communication path and fluids including oil are recovered from the production well until the fluid recovered contains an unfavorable ratio of oil to solvent. The production well is shut-in and an additional quantity of the hydrocarbon solvent is injected into the fluid communication path, preferably until a total amount of between 0.03 to 0.30 pore volume has been injected. The injection well is then shut-in along with the production well to permit the formation to undergo a soak period for a variable time, preferably for a time of between 2 to 20 days per vertical thickness in feet of oil-containing formation. A driving fluid such as water is then injected into the formation via the injection well and the oil is produced until there is an unfavorable ratio of oil to driving fluid. During the fluid drive recovery phase, the injection well and production well may be completed to be in fluid communication with the entire portion of the formation to obtain a more uniform displacement of the solvent and oil mixture in the formation by the driving fluid.

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In U.S. Patent No. 4,293,235 of J.L. Fitch, issued October 6, 1981, there is disclosed a method of recovering viscous oil from a viscous oil bearing subsurface formation wherein a solvent is injected into a high mobility channel formed in the bottom of the formation intermediate an injection well and a production well. The solvent is injected until the ratio of produced oil to solvent becomes unfavorable and thereafter the injection of solvent is terminated and gas is injected into the high mobility channel to produce solvent and oil from the formation.

In U.S. Patent 3,836,738 there is described a method for recovering viscous petroleum from petroleum-containing formations by first establishing a fluid communication path low in the formation. A heated fluid is then injected into the fluid communication path followed by injecting a volatile solvent such as carbon disulfide, benzene or toluene into the preheated flow path and continuing injecting the heated fluid and recovering fluids including petroleum from the production well.

In U.S. Patent 3,500,917 there is disclosed a method for recovering crude oil from an oil-bearing formation having a water-saturated zone underlying the oil-saturated zone. A mixture of an aqueous fluid which has a density greater than the density of the crude oil and a solvent having a density less than the density of the crude oil are injected into the water-saturated zone and oil is produced from the formation.

U.S. Patent 4,026,358 discloses a method for recovering heavy oil from a subterranean hydrocarbon-bearing formation traversed by at least one injection well and one production well wherein a slug of hydrocarbon solvent in amounts of 0.1 to about 20 percent of the formation pore volume and having a gas dissolved therein is injected into the formation via the injection well. Thereafter, a thermal sink is created in the formation by in-situ combustion or by injecting steam. The wells are then shut-in for a predetermined time to permit the formation to undergo a soak period, after which production is continued. Optionally, after the production period, the formation may be water flooded to recover additional oil from the formation.

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This invention is directed to a method of recovering viscous oil from a viscous oil-containing formation that has no significant vertical permeability barrier in the portion of the formation being produced involving at least one injection well and at least one spaced-apart production well that vertically penetrate the formation and then extend horizontally through the bottom of the formation for injection of a predetermined amount of solvent into the formation and recovery of oil from the formation. The injection well and production well are drilled into the formation extending downwardly from the earth's surface to the bottom of the oil-containing formation and then a substantial distance through the formation in a generally horizontal direction. That portion of the injection well and production well that extends horizontally through the bottom of the formation is perforated or otherwise equipped to provide fluid communication between both wells and the formation. The production well is spaced-apart from the injection well but the horizontal portion of the production well is at the same level as, and parallel to, the horizontal portion of the injection well. A predetermined amount of hydrocarbon solvent having a viscosity not greater than 1/100 the viscosity of the oil contained in the formation and a specific gravity less than the oil contained in the formation under formation conditions, is injected into the bottom of the formation via the injection well and fluids including oil are recovered from the production well. The amount of solvent injected is preferably 0.05 to 0.30 pore volume. After the desired amount of solvent has been injected into the formation, production is terminated and both the injection well and production well are shut-in to permit the formation to undergo a soak period for a variable time, preferably for a period of time between 2 to 20 days per foot of vertical thickness of the oil-containing formation. During this soak period, the light hydrocarbon solvent will tend to rise and the heavy oil will move downward in a gravity-driven convection process forming a pattern of fingers. This fingering causes an effective contact between the oil and solvent thus providing a greater volume of oil that is reduced in viscosity thereby increasing the rate of oil recovery. Thereafter, a

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driving fluid such as water is injected into the injection well to displace the oil of reduced viscosity toward the production well for recovery. Production is continued until the oil recovered from the production well contains an unfavorable amount of driving fluid, preferably at least 90 percent.

The term "viscous oil" is used herein to identify oil having relatively high viscosity and includes those oils referred to as tars. Such viscous oils are also referred to as heavy oils. In general, the term viscous oil is used to include those heavy oils and tars such as are commonly found in formations referred to as heavy oil or tar sands that have viscosities that are great enough to severely restrict the production of the oils from the formations in which they are found. The API gravity of such viscous oils is normally 20° API or less.

In the accompanying drawings:

Figure 1 is a diagrammatic plan view of an area which overlies an oil-containing formation, and indicates by dotted lines an injection well and a production well which extend downwardly from the surface to the bottom of the oil-containing formation;

Figure 2 is a sectional view taken along the line 2-2 in Figure 1 showing the manner in which the injection well and production well penetrate the formation; and

Figure 3 is an isometric view of a rectangular block of the earth showing the position of the injection well and the production well within the formation.

Referring to the drawings, a field 10 overlying an oil-containing formation is provided with an injection well 12 and a production well 14. As shown in Figures 2 and 3, the injection well 12 and the production well 14 extend downwardly from the earth's surface 16, through an overburden 18, into the oil-containing formation 20 and then extend a substantial distance horizontally through the bottom of the formation. The production well 14 is spaced apart from the injection well 12 and the horizontal portion of the production well 14 is at the same level and parallel to the horizontal portion of the injection well. The horizontally extending portion of the injection

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well 12 and the production well 14 have perforations 22 providing fluid communication between that portion of each well and the lower portion of the formation 20. Although only one injection well and one production well are shown for purposes of illustration, it is understood that a plurality of alternating spaced apart injection wells and production wells may be used in our process with the number depending upon the characteristics of the oil-containing formation. The wells may be formed by conventional directional drilling means with the horizontally extending portion of each well in the bottom of the formation being within plus or minus 20° or more preferably within minus 20° of a horizontal plane.

A predetermined amount of solvent having a specific gravity less than the specific gravity of the oil contained in the formation and having a viscosity not greater than 1/100 of the viscosity of the oil contained in the formation under formation conditions is injected into the bottom of the formation via the injection well 12 and fluid including oil is recovered from the formation via production well 14. The amount of solvent injected into the formation during this step is preferably within the range of 0.05 to 0.30 pore volume. Once this amount of solvent has been injected, the injection well 12 and the production well 14 are shut-in and the formation 20 is allowed to undergo a soak period for a predetermined time, preferably for a period of time between 2 to 20 days per foot of vertical thickness of the oil-containing formation. It will be recognized by those skilled in the art of oil recovery that during this shut-in or soak period minor amounts of fluid may be injected or produced, such as for the purpose of testing, without significant detrimental effects on the process. During this soak period, the liquid hydrocarbon solvent being lighter than the oil contained in the viscous oil-containing formation, that is, having a specific gravity less than the specific gravity of the oil contained in the formation and having a viscosity not greater than 1/100 of the viscosity of the oil contained in the formation under formation conditions, will tend to flow by gravity-driven convection upward into the oil-containing formation and the heavy oil will flow by

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gravity-driven convection downward to form a pattern of fingers. This fingering is important in that the distribution, size and extension of these fingers will provide intimate contact between the solvent and the heavy oil allowing the two to mix more effectively, thus forming a greater volume of oil that is reduced in viscosity and which can be produced more readily. This relatively low viscosity mixture can be much more effectively displaced from the reservoir than the original heavy oil by flooding the formation with water or other suitable fluid, as is well known to those skilled in the art of petroleum engineering.

Once the soak period has been completed, a driving fluid is injected into the formation 20 via the injection well 12 and oil of reduced viscosity is recovered from the production well 14. The driving fluid displaces the mobilized oil from the formation 20 into the production well 14 and production is continued until the recovered oil contains an unfavorable amount of driving fluid, preferably at least 90 percent. The driving fluid may be gaseous or liquid. Suitable gases include light aliphatic hydrocarbons having from one to four carbon atoms, carbon dioxide and nitrogen. Aqueous fluids are particularly preferred driving fluids and water, brine and thickened aqueous fluids are suitable aqueous driving fluids.

The hydrocarbon solvents used in our process must have a specific gravity less than that of the oil and less than that of the brine injected or naturally present in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions. It is also highly desirable that the hydrocarbon solvent remain liquid under the temperature and pressure conditions that exist in the subsurface viscous oil-containing formation and not cause solids such as asphaltenes to precipitate from the oil in amounts sufficient to seriously plug the pores of the formation. The preferred hydrocarbon solvent is a light crude oil. Other examples of suitable hydrocarbon solvents include light oil condensates having an API gravity greater than 30 API degrees and partially refined tar which is generally known as syndrude. It may be desirable to include in the hydrocarbon solvent up to about 10 percent

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of aromatic material such as aromatic refinery stock to make the solvent compatible with the oil contained in the formations and to prevent the deposition of solid or gelatinous materials such as asphaltenes therefrom.

The viscous oil-containing subsurface formation to be treated by the present hydrocarbon solvent recovery method must be one that has no significant vertical permeability barriers in that portion of the formation to be treated. This allows the solvent that is injected into the lower portion of the formation between the injection well and production well to flow upward into the formation by convection forces thus solubilizing the oil and forming a solvent-oil mixture of reduced viscosity that can be more readily produced by a fluid drive process.

In a further embodiment, the injection well and the production well may extend downwardly from the earth's surface into the bottom of the oil-containing formation with the lower portion of each well extending through the formation at a downward angle not greater than 20° relative to a horizontal plane and the lower portion of each well in fluid communication with the formation. The production well is spaced apart from the injection well and the lower portion is at the same level and parallel to the lower portion of the injection well.

By the term "pore volume" as used herein, is meant that volume of the portion of the formation underlying the well pattern employed as described in greater detail in U.S. Patent No. 3,927,716 to Burdyn et al., issued December 23, 1975.

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CLAIMS:

1. A method of recovering viscous oil from a subterranean viscous oil-containing formation having no significant vertical permeability barrier therein comprising the steps of:

- (a) providing at least one injection well extending downwardly from the earth's surface to the bottom of said oil-containing formation wherein the lower portion of the well extends through the formation at an angle not greater than 20° relative to a horizontal plane;
- (b) providing at least one production well extending downwardly from the earth's surface to the bottom of said oil-containing formation wherein the lower portion of the well extends through the formation at an angle not greater than 20° relative to a horizontal plane, said production well being spaced from said injection well but the lower portion of said production well being generally at the same level as, and being generally parallel to, the lower portion of said injection well, and said injection well and said production well being in fluid communication with the lower portion of said formation;
- (c) injecting a predetermined amount of hydrocarbon solvent into the formation via said injection well, said solvent having a specific gravity less than the specific gravity of the oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions and recovering fluids including oil from the formation via said production well;

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(d) thereafter, shutting-in said injection well and said production well to permit said formation to undergo a soak period for a predetermined period of time wherein the solvent mixes with the oil in the formation by gravity-driven convection to reduce the viscosity of the oil; and

(e) thereafter injecting a driving fluid into the formation via said injection well and recovering fluids including oil of reduced viscosity from said formation via said production well until the fluid being recovered from the production well comprises an unfavorable amount of driving fluid.

2. The method of Claim 1 wherein the total amount of solvent injected during step (c) is between 0.05 and 0.30 pore volume and the soaking period during step (d) is for a period of time between 2 and 20 days per foot of vertical thickness of the oil-containing formation.

3. The method of Claim 1 wherein the driving fluid injected during step (e) is a gaseous material selected from the group consisting of carbon dioxide, nitrogen or aliphatic hydrocarbons having one to four carbon atoms.

4. The method of Claim 1 wherein the driving fluid injected during step (e) is water.

5. The method of Claim 1 wherein said hydrocarbon solvent is selected from the group consisting of a light crude oil having an API gravity greater than 30 API degrees and a light crude oil product generally known as syncrude.

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6. The method of Claim 1 wherein production of fluids from the formation by the production well according to step (e) is continued until the fluid recovered contains at least 90 percent driving fluid.

7. A method of recovering viscous oil from a subterranean viscous oil-containing formation having no significant vertical permeability barrier therein comprising the steps of:

- (a) providing at least one injection well extending downwardly from the earth's surface to the bottom of said oil-containing formation and then extending outwardly a substantial distance through said formation in a generally straight horizontal direction;
- (b) providing at least one production well extending downwardly from the earth's surface to the bottom of said oil-containing formation and then extending outwardly a substantial distance through said formation in a generally straight horizontal direction, said production well being spaced from said injection well and the generally straight horizontal portion of said production well being generally at the same level as, and being generally parallel to, the generally straight horizontal portion of said injection well, and said injection well and said production well being in fluid communication with the formation over the distance of each well extending through said formation in a generally straight horizontal direction;
- (c) injecting a predetermined amount of hydrocarbon solvent into the formation via said injection well, said solvent having a

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- specific gravity less than the specific gravity of the oil contained in the formation and a viscosity not greater than 1/100 the viscosity of the oil contained in the formation under formation conditions and recovering fluids including oil from the formation via said production well;
- (d) thereafter, shutting-in said injection well and said production well to permit said formation to undergo a soak period for a predetermined period of time wherein the solvent mixes with the oil in the formation by gravity-driven convection to reduce the viscosity of the oil; and
- (e) thereafter injecting a driving fluid into the formation via said injection well and recovering fluids including oil of reduced viscosity from said formation via said production well until the fluid being recovered from the production well comprises an unfavorable amount of driving fluid.

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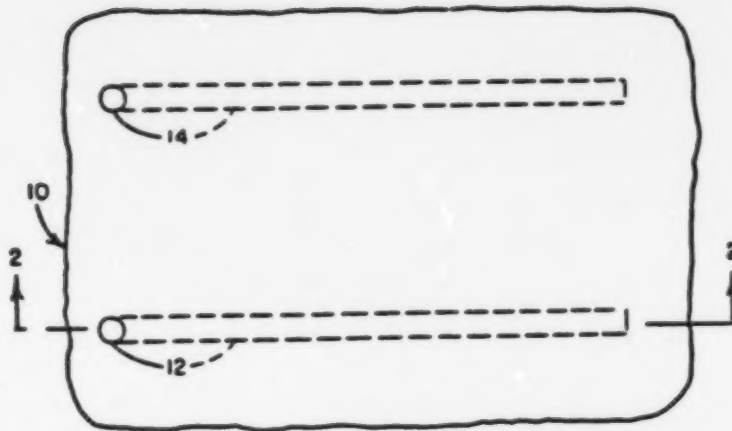


FIG. 1

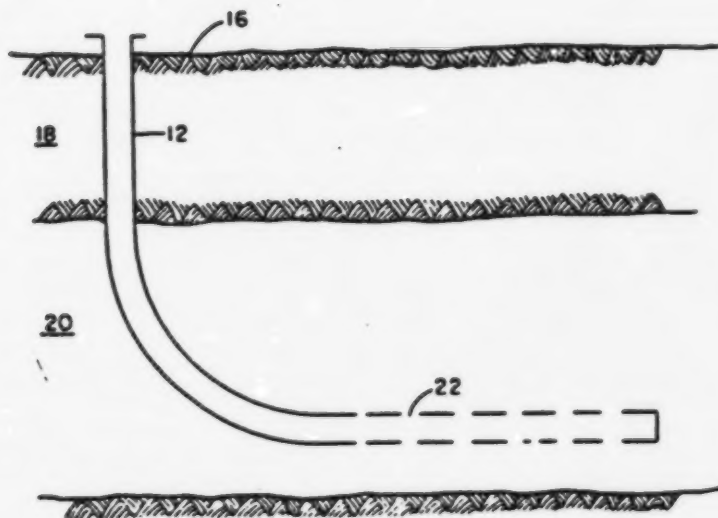
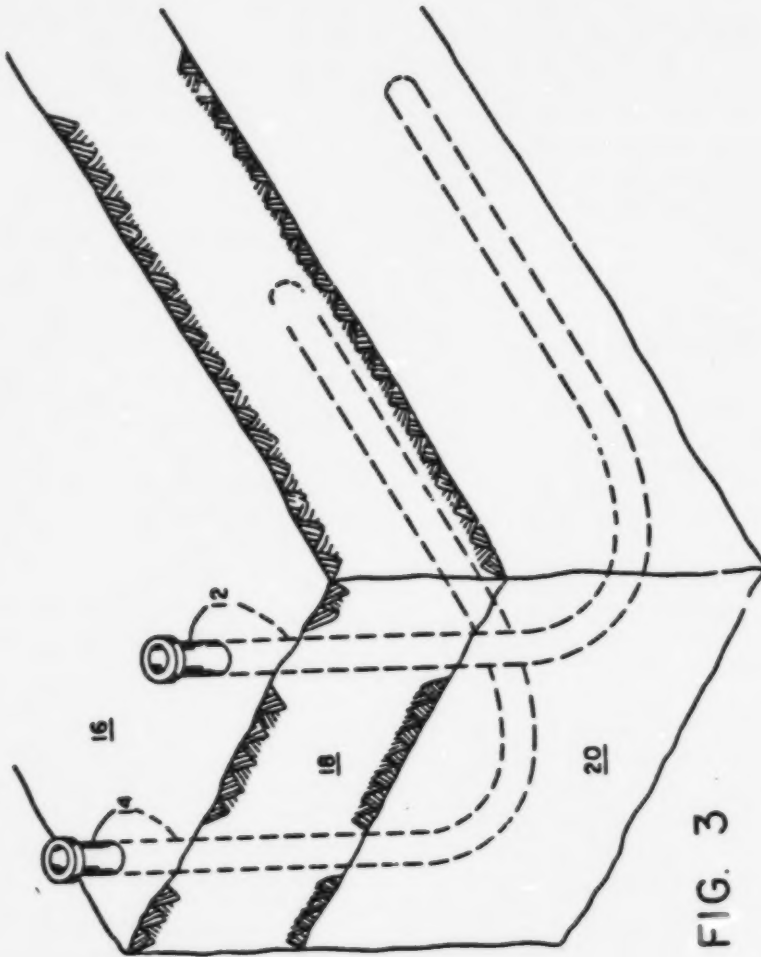


FIG. 2

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United States Patent [19]

Shu et al.

[11] **Patent Number:** 4,598,770[45] **Date of Patent:** Jul. 8, 1986[54] **THERMAL RECOVERY METHOD FOR VISCOUS OIL**[75] **Inventors:** Winston R. Shu, Dallas; Kathy J. Hartman, Arlington, both of Tex.[73] **Assignee:** Mobil Oil Corporation, New York, N.Y.[21] **Appl. No.:** 664,740[22] **Filed:** Oct. 25, 1984[51] **Int. Cl.:** E21B 43/24[52] **U.S. Cl.:** 166/245; 166/50;

166/52; 166/272

[58] **Field of Search:** 166/272, 263, 303, 50, 166/52, 245[56] **References Cited****U.S. PATENT DOCUMENTS**

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4,344,485	8/1982	Butler	166/50 X
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4,434,849 3/1984 Allen 166/50 X

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Oil and Gas Journal, Aug. 23, 1982, pp. 51-54.

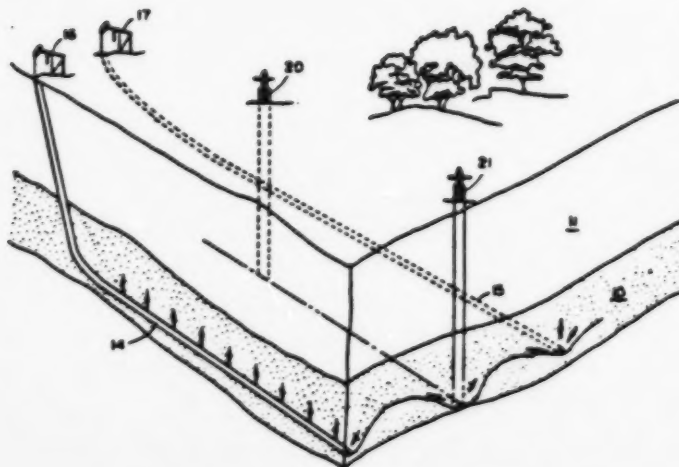
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Primary Examiner—Stephen J. Novosad
Attorney, Agent, or Firm—A. J. McKillop; Michael G. Gilman; George W. Hager, Jr.

[57] **ABSTRACT**

A thermal oil recovery process in which steam is injected into a heavy oil-bearing formation through a horizontally-drilled injection well and oil is produced through a horizontal production well parallel to the injection well.

2 Claims, 5 Drawing Figures

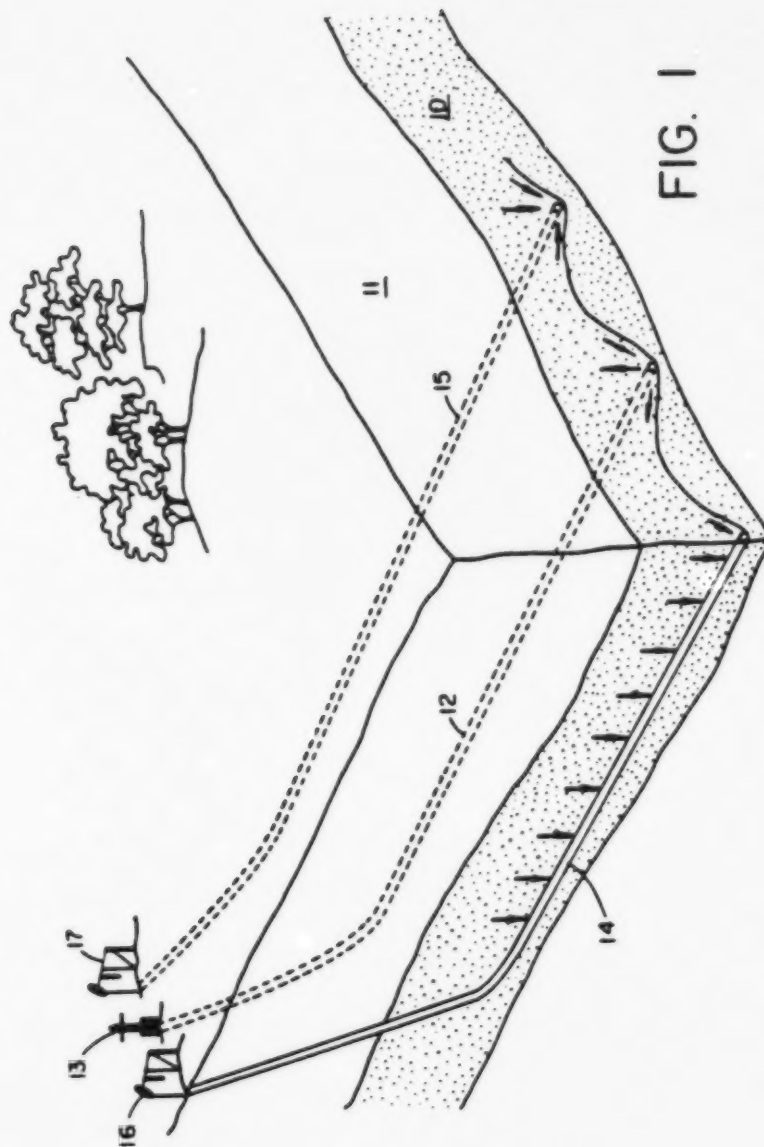


FIG. 1

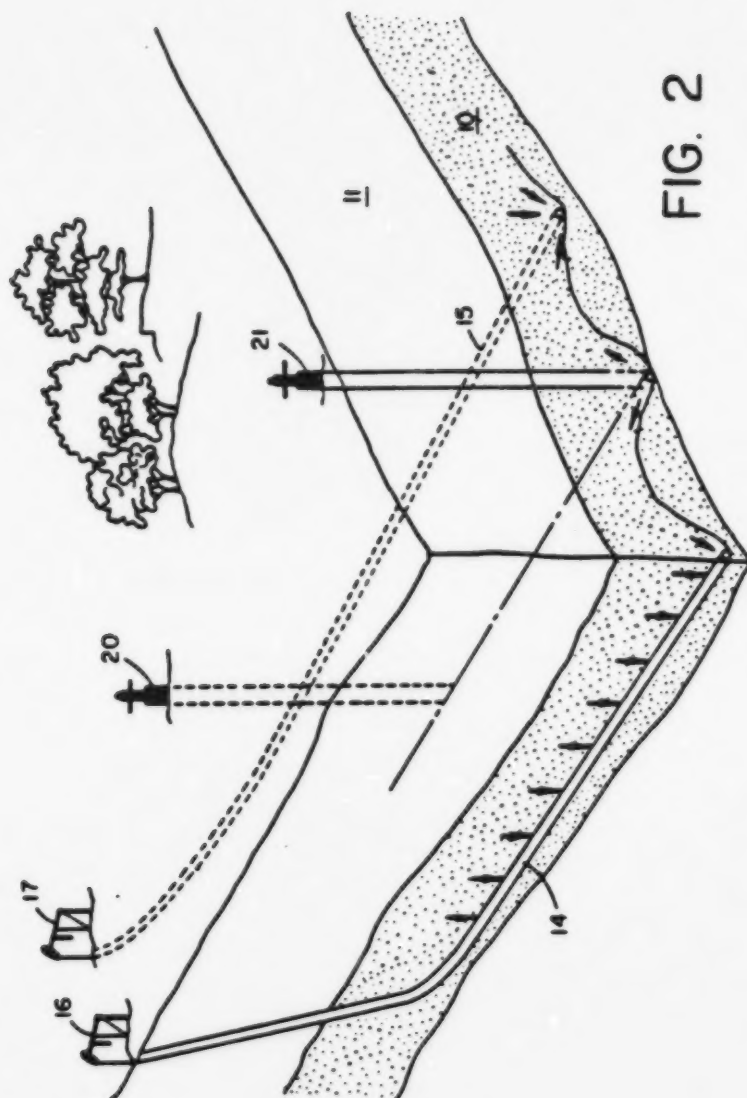


FIG. 2

FIG. 3

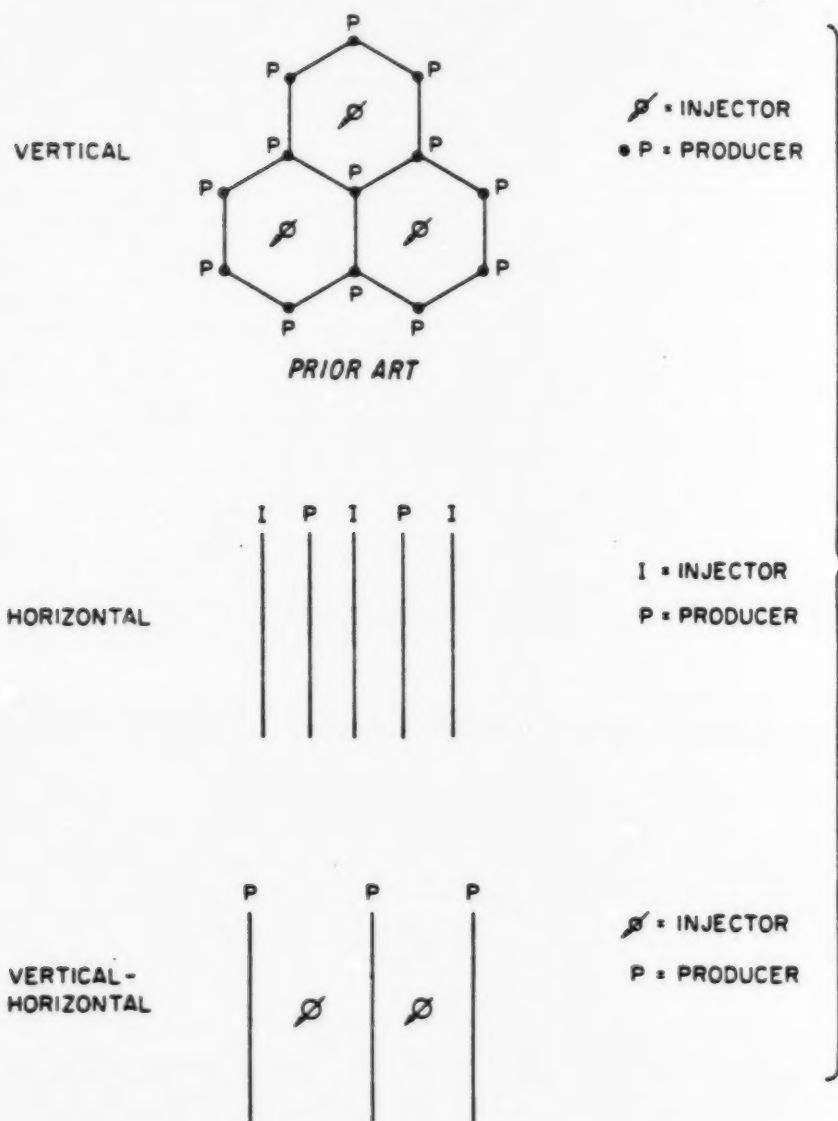


FIG. 4

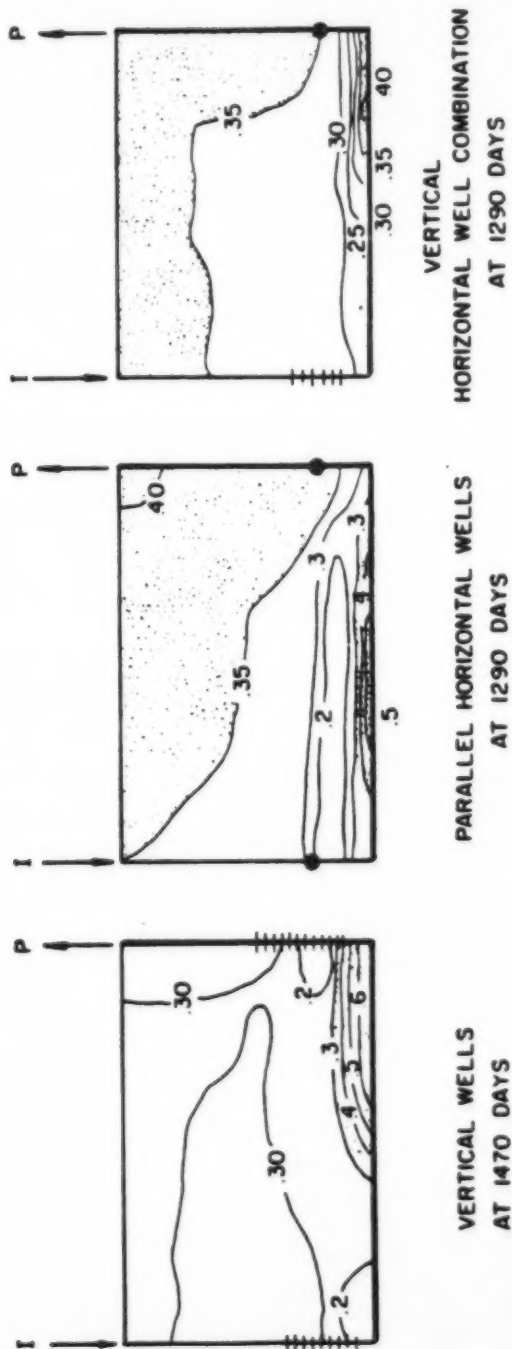
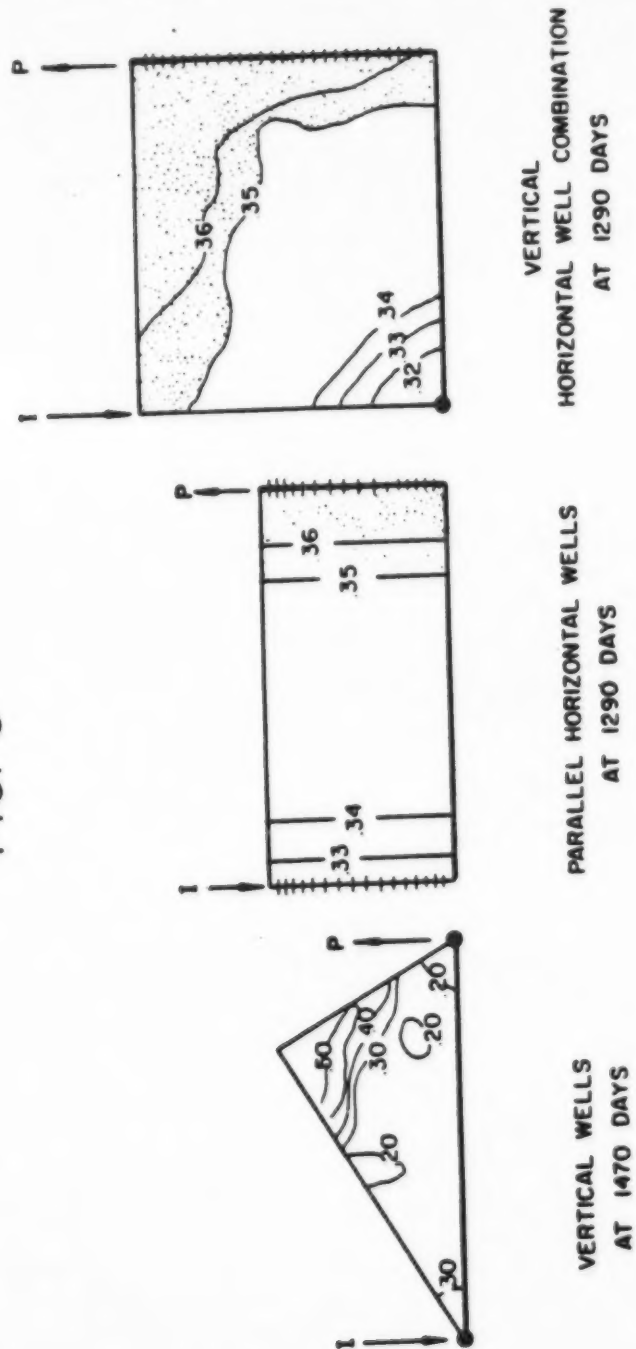


FIG. 5



THERMAL RECOVERY METHOD FOR VISCOUS OIL

FIELD OF THE INVENTION

This invention relates to a thermal recovery process for recovering viscous oils from subterranean formations. In particular, the invention relates to an improved steam flooding method for recovering such oils.

BACKGROUND OF THE INVENTION

There are many subterranean formations containing heavy, i.e. viscous, oils from which the oil cannot be recovered by conventional methods because the oil is too viscous to flow to the production wells without some form of assistance. Such formations are known to exist in the major tar sand deposits of Alberta, Canada and Venezuela with lesser deposits elsewhere, for example, in California, Utah and Texas. The API gravity of the oils in these deposits typically ranges from 10° to 6° in the Athabasca, Alta. deposits to even lower values in the San Miguel sands in Texas, indicating that the oil is of a highly viscous nature.

Various methods have been proposed for recovering the oil in these deposits now that reserves of more easily recovered oils are decreasing, at least in the politically stable areas of the world. These methods include in-situ combustion methods in which part of the oil in the reservoir is burnt by the injection of air or oxygen through an injection well to generate heat so as to reduce the viscosity of the oil and to produce a degree of cracking; the resulting less viscous, cracked oil then acts as a solvent for the heavy oil in place. Solvent recovery techniques have also been proposed, for example in U.S. Pat. Nos. 4,373,585 and 4,293,035, in which a solvent for the heavy oil is injected into the reservoir to form a less viscous solution which can then be recovered by more conventional means. Another technique which has been proposed and used in various forms is steam flooding, in which steam is injected into the formation through an injection well, to heat the formation and, in so doing, to reduce the viscosity of the oil and possibly also, to induce a degree of cracking, resulting in a further reduction in viscosity. Processes of this type can be generally classified as basically of the two well or one well type. In the two well or steam drive type, the steam is injected through an injection well and the injected steam serves to drive the oil towards a separate production well which is located at some horizontal distance (offset) from the injection well. In the one-well or "huff and puff" type operation, a single well is used for both injection and production. The steam is first injected to reduce the viscosity of the oil and to pressurize the formation; after a certain amount of time, steam injection is terminated and the well is turned over to production. A soak period may be allowed to permit the heat to permeate the reservoir to a greater extent before production is initiated in either type of operation. Whether the process is classified as of the one-well or two well types, the well arrangement can, of course, be repeated to cover the field in the manner desired. For example, the two well arrangement may be repeated in regular patterns such as the inverted five spot or inverted seven spot patterns, as described in U.S. Pat. No. 3,927,716. The present method relates basically to the two well type operation, using an injection well or wells and a

separate production well or wells at an offset from the injection well.

Horizontally drilled wells have been proposed in various applications, for example, in solvent recovery processes, as described in U.S. Pat. No. 4,385,662 as well as for offshore primary recovery operations as described, for example, in Ocean Industry, June 1984, 35-36 and in certain steam flooding operations mentioned in the Ocean Industry article.

Among the steam flooding operations using horizontal wells are the Kern River, California "huff and puff" project described in the Oil and Gas Journal, 23 August 1982, 51-54, this project also including conventional vertical steam injection wells bisecting the lateral wells. The Cold Lake, Alta. project which used horizontal wells is believed to be of the single well ("huff and puff") type also; the project has been described in Paper No. 79-30-10 of the Petroleum Society of CIM, presented in Banff, Alta. 8-11 May 1979. A similar project was operated at Fort McMurray, Alta., as described in Paper No. 82-33-68 of the Petroleum Society of CIM, presented 6-9 June 1982 in Calgary, Alta., Petroleum Engineer International, September 1982, 40-52. In addition, U.S. Pat. No. 4,248,302 discloses a steam flood recovery method using a highly deviated injection well with production wells situated along the line of the injection well. This proposal has the disadvantages that not only is a relatively large number of production wells required but, in addition, correct positioning of these wells over the injection points is difficult.

Steam flooding processes using horizontal fractures for injecting the steam have been proposed in U.S. Pat. Nos. 3,375,870 and 4,265,310.

U.S. Pat. No. 4,466,485 describes a viscous oil recovery method which employs a steam injection well which extends through the formation in a horizontal direction. The production well is in the conventional vertical position and is completed in the upper two-thirds of the formation. A particular production cycle is employed to maximize recovery but because of the vertical disposition of the production wells, complete drainage of the formation is not assured.

SUMMARY OF THE INVENTION

According to the present invention, viscous oils are recovered from subterranean formations by a steam flooding operation using at least one horizontally drilled production well. The steam may be injected either through injection wells arranged vertically in the conventional manner, at an offset from the horizontal production well or, alternatively, a horizontal injection well may be used. Generally, it is preferred that the injection wells should be arranged along a line between two of the horizontal production wells in order to achieve maximum steam utilization and to optimize reservoir drainage into the production wells. The production wells will normally be situated near the bottom of the production interval to ensure that drainage is as complete as possible, thereby maximizing recovery.

DRAWINGS

FIG. 1 is a simplified representation of a recovery operation using horizontal injection and production wells;

FIG. 2 is a simplified representation of a recovery operation using horizontal production wells and vertical injection wells;

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FIG. 3 is a schematic showing the well patterns used in the experimental simulations described below;

FIG. 4 is a comparison of the residual oil saturations obtained with the simulated production runs described below (vertical contours);

FIG. 5 is a comparison of the residual oil saturations obtained with the simulated production runs described below (horizontal contours).

DETAILED DESCRIPTION

FIG. 1 shows the preferred well pattern for carrying out the present production method. A subterranean heavy oil formation 10 underneath an overburden 11 has a horizontal steam injection well 12 extending from surface injection head 13 in a substantially straight line along the bottom of the production interval. Two horizontal production wells 14, 15 also run through reservoir 10 at the bottom of the production interval, with their horizontal portions parallel to injection well 12. At the surface, the production wells are connected to suitable wellhead equipment 16, 17 for producing the fluids which enter the wells.

In operation, steam is injected into injection well 12 and thence into formation 10 where it heats the formation and the oil in place in the reservoir to the appropriate temperature for recovery through the production wells.

An alternative arrangement is depicted in FIG. 2 in which vertical steam injection wells 20, 21 are disposed along a line parallel to and centrally between horizontal production wells 14, 15. The injector wells are completed at the bottom of the production interval and the horizontal production wells again, run along the bottom of the production interval. Wellhead equipment 16, 17 is provided as previously described.

Because the steam from the injector wells tends to rise in the reservoir after it leaves the injection well, the injection wells should preferably be completed in the lower portion of the production interval. However, to minimize heat losses to the non-pay zone beneath and to minimize channelling of steam under the pay zone, it may be desirable to position the horizontal injection well or to complete the vertical injection well, as appropriate, somewhat above the bottom of the production interval; e.g. at 80% or 90% of the vertical distance down the interval. Because the oil which has been heated by the steam will descend through the reservoir, taking with it some of the oil in place, positioning the injector at some distance up in the reservoir will not necessarily lose production because the descending, heated oil, together with entrained reservoir oil, will drain into the production wells at the bottom of the interval. Thus, the use of the horizontal producing wells establishes a vertical sweep of high efficiency in the reservoir. Area sweep may be up to almost 100 percent because of the greater reservoir area exposed to the producing wells.

The horizontal separation or offset between the line of injectors and the production wells needs to be chosen according to reservoir characteristics; e.g. nature of oil, matrix porosity, permeability and so forth. This may be determined by reference to the known characteristics of the reservoir prior to siting the wells. The well pattern may, of course, be repeated in order to cover the production field to the extent desired. Generally, it has been found that one horizontal well can replace about 2.5 to 3.8 vertical wells in a parallel horizontal injector/producer pattern, depending upon the vertical per-

meability of the formation; in a vertical injector/horizontal producer operation, one horizontal well can generally replace about 1.6 to 2.4 vertical producers. In an infinitely repeated vertical injector/horizontal parallel producer pattern, the injectors should be situated on the center line between the parallel producers with a separation equal to the separation between the producers. In this case, therefore, the number of vertical injectors between each pair of producers will be equal to the quotient of the length of the horizontal producers and their separation. The economics of the operation should therefore be considered at the outset since horizontal wells are more expensive to drill than vertical wells. The advantages of horizontal wells over vertical wells increase with an increasing ratio of vertical to horizontal permeability for the reservoir: as the ratio increases, residual oil saturation in the upper part of the reservoir will decrease, to give a better vertical sweep efficiency resulting from the improved drainage into the production wells.

Operating conditions for the steam flooding process should be chosen in accordance with known reservoir characteristics such as permeability, nature of oil and so forth. The operating procedure may follow conventional principles or may be adjusted suitably to take the greatest opportunity of exploiting the advantages of the present invention. For example, steam injection rates may typically be from 1.5 to 2.0 barrels/day/acre-foot CWE (cold water equivalent) (from about 385 to 260 l./day/1000 m³ CWE). Total amount of steam injected will depend primarily on reservoir thickness, temperature and thermal conductivity together with the characteristics of the oil; e.g. the extent to which it is affected physically and chemically by the steam. Typically, steam temperature will be from 200° to 400° C. (about 400° to 750° F.); temperatures at the higher end of this range will generally tend to promote cracking of the oil in the reservoir to produce a vis-broken oil of low viscosity which facilitates an enhanced degree of recovery of the reservoir oil, as compared to a non-visbroken oil that has merely been subjected to heating by lower temperature steam. Steam temperature is determined by its pressure of injection which, in turn, will depend upon the reservoir characteristics; e.g. reservoir pressure and can be readily determined. Steam quality may also be selected according to the desired amount of net heat to be injected but normally should lie between 0.4 to 0.8 for a safe and efficient operation of the steam generator.

The production operations may be run with either rate control or pressure control. In the former, a predetermined liquid flow rate is maintained by adjusting the bottomhole pressure at the injector. With pressure control, free flow of liquids is allowed by maintaining constant bottomhole pressure, assuming that pump capacity is adequate to remove all the fluids produced. Depending upon reservoir characteristics, it may be more advantageous to operate with rate control in order to achieve maximum production, although it may take longer to do it; the economics of the individual modes of operation should therefore be given appropriate consideration in each case.

Experimental

Vertical Well Pattern

Using computer modelling techniques, a reservoir volume equivalent to about one-twelfth of an infinitely

repeated seven spot vertical well pattern was simulated, as shown in FIG. 3. The model therefore assumed use of 1/12 of the injector and 1/6 of a producer. The equivalent area for the pattern was 6.9 acres (2.8 ha) thus giving a simulated area of 0.575 acre (0.23 ha), at a well distance of 341 ft (104 m).

The injector was completed in the 195 ft (59 m) pay zone for an interval of 60 ft (18.3 m) and the producer 90 ft (27.4 m), each starting just above a 15 ft (4.6 m) water layer ($S_w=0.81$). Initial reservoir temperatures were 60° C. (140° F.) and 790 kPa (100 psig), respectively.

Steam of 60% quality was injected at 285° C. (545° F.) and 3200 kPa (450 psig), respectively, at an injection rate of 376 hl/day (237 bbl/day) for one-twelfth of an injector. The production well was placed on rate control with a maximum liquid rate of 477 hl/day (300 bbl/day), equivalent to 211 l/day/1000 m³ (1.65 bbl/day/acre-foot).

Criteria used for determining the time of steam breakthrough were: live steam production, a significant drop in the oil production rate and a significant increase in the water-oil ratio (water:oil greater than 20:1).

Horizontal Well Pattern

A parallel horizontal well pattern, i.e., an infinitely repeated pattern of injectors and producers horizontal and parallel to one another, as shown in FIG. 3, of equivalent surface area to 1/6 of the vertical well pattern, using the same well separation of 104 m (341 ft). The resulting length of horizontal well simulated was therefore 45.3 m (148.5 ft). To cover an area equivalent to the entire seven spot vertical pattern, the horizontal wells would be six times as long, about 271 m (891 ft). The horizontal wells were placed 12 m (40 ft) from the bottom of the pay zone.

The injection of steam was simulated using the same conditions as for the vertical well pattern.

For simulation purposes, the horizontal well pattern was tested with both rate control and pressure control.

Vertical-Horizontal Well Combination

An infinitely repeated well pattern having vertical injection wells and horizontal producers, as shown in FIG. 3, was also simulated. In this case, simulated area was equivalent to one quarter of the 7-spot vertical pattern, using a horizontal offset of 90 m (295 ft) between the vertical injector and the horizontal producer. The vertical well was completed for 18.3 m (60 ft) in the pay zone, as in the vertical well situation, and the horizontal well was situated 10.7 m (35 ft) above the water layer. The length of the horizontal well in the simulated area was about 152 m (500 ft).

Steam injection was simulated under the same conditions as for the other cases, using both rate and pressure control. The results are given in Table 1 below.

TABLE 1

Comparison of Well Patterns			
Pattern	Vertical	Horizontal	Vertical-Horizontal
Breakthrough Time, Days	1470	1290	1290
Injection, MBBL	3862	3471	3472
Production			
Oil, MBBL	575.0	481.4	455.4
Oil, %	33.5	28.0	26.5

TABLE 1-continued

Comparison of Well Patterns			
Pattern	Vertical	Horizontal	Vertical-Horizontal
Water, MBBL	4175.4	4053	4232
Ratio			
Oil/Steam	0.149	0.139	0.124
Cumulative Water/Oil	7.26	8.42	9.29

Notes:
(1) Injection and Production figures on equivalent 7-spot average basis.
(2) Percentage oil produced is percentage of original oil in place.
(3) Results for horizontal and vertical/horizontal patterns are on pressure control.

With the parallel horizontal well pattern under pressure control, breakthrough occurred, as shown in Table 1 at 1290 days. Under rate control, breakthrough occurred later (at 1470 days) but gave a higher total oil recovery, indicating that for the reservoir studied there is likely to be an optimum production rate between the cases considered in this study.

With the vertical/horizontal well pattern, a similar result was obtained in the comparison between rate and pressure control.

Comparison of the residual oil saturation contour plots at steam breakthrough shown in FIGS. 4 and 5 indicates that each type of well pattern has a different sweep pattern. FIG. 4 compares the oil saturation contours showing the vertical sweep in the plane which contained the vertical injector. All well patterns had poor vertical sweep in areas beneath the production well elevation. The vertical well pattern had excellent vertical sweep with steam overriding and pushing oil over and down to the producer. The parallel horizontal wells had less steam override and less recovery from the upper portion of the reservoir. The vertical-horizontal well combination showed an intermediate vertical sweep with more override near the vertical injector and less near the horizontal producer.

FIG. 5 illustrates the area sweep in the horizontal plane which contained the horizontal wells, at steam breakthrough. The vertical wells left some unswept oil between two producers in the 7-spot pattern. The area sweep of the horizontal wells is, of course, uniform for a two-dimensional simulation. The combination well pattern shows a somewhat intermediate area sweep. Steam front advance is very like plug flow in blocks directly between the vertical injector and the horizontal producers. It also shows a region of unswept oil in the corner opposite the vertical injector.

We claim:

1. In a method for the enhanced recovery of a viscous oil from a subterranean, oil-bearing formation by injecting steam into the formation through at least one injection well and producing oil from a plurality of separate producing wells situated at an offset from the injection well, the improvement which comprises

(a) a plurality of substantially parallel horizontal production wells, and

(b) a plurality of vertical injection wells located between each pair of adjacent parallel horizontal production wells and spaced apart along the center line between each of said pairs of parallel horizontal production wells at distances equal to the separation of said parallel horizontal production wells.

2. A method according to claim 1 in which the number of said plurality of vertical injection wells situated between each pair of adjacent parallel horizontal production wells is equal to the quotient of the length of said parallel wells and the separation between said production wells.

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